A History of Fruit Fly Research

By the Agricultural Research Service in Hawaii

By ARS Technician Hank Soboleski
And all Agricultural Research Service Hawaii Scientists, Technicians, and Administrative Support Personnel Past and Present

Medfly. ARS photo.

Edited by Dr. Eric Jang and Dr. Ernest J. Harris

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United States Pacific Basin Agricultural Research Center
920 Stainback Highway
Hilo, Hawaii 96720

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Contents

Acknowledgments

We thank current staff of the US Pacific Basin Agricultural Research Center: entomologists Dr. Ernest J Harris, Dr. Eric Jang, Dr. Roger Vargas, Dr. Jack Armstrong, and Dr. Peter Follett; biologist Dr. Grant McQuate; geneticist Dr. Don McInnis, and Dr. Chiou Ling Chang; and technicians Lori Carvalho, Les Oride, and Rick Kurashima for their help on this project.

Of these, a special thank you must be given to Dr. Harris, whose wisdom, kindness, and over 40 years of service with ARS in Hawaii proved to be especially helpful.

Also, a special "aloha" is passed along to the retired Agricultural Research Service staff: Dr. Roy T. Cunningham, Dr. Harvey Chan, Norimitsu "Nori" Tanaka, Richard Kobayashi, Doris Miyashita, Clifford Lee, Martin Fujimoto and Shizuko "Sue" Mitchell.

Former ARS employees Larry Nakahara, and Harris Chang have also shared their valuable recollections.

Thanks also to retired Beltsville, Maryland chemist and ARS Hall of Fame honoree Dr. Morton Beroza, who supplied rare photographs and unique insight, and Center Director Dennis Gonsalves and Norma Ross of the Hilo Administrative Office, and all those who made this project possible.

Forward

Research on tephritid fruit flies in Hawaii has a long and proud history that dates back to the introduction of the melon fly in 1895. In the hundred plus years since then, many of the key discoveries leading to the effective management of fruit flies worldwide have been directly or indirectly influenced by the dedicated USDA researchers in Hawaii who have led the way. During this time, various organizational changes have resulted in numerous name changes from the Hawaii Fruit Fly Investigations Laboratory to the Tropical Fruit, Vegetable and Ornamental Crops Research Laboratory, all the while having a focus almost solely on fruit flies. In 1999, a major organizational change occurred which consolidated several ARS research groups to what is now known as the U.S. Pacific Basin Agricultural Research Center (PBARC). While a significant part of the overall research program still focuses on fruit flies, other research on molecular plant pathology and tropical germplasm, and a broader focus on pests and diseases that affect agriculture in Hawaii and the Pacific have taken place. In discussions with past and present colleagues we thought it might be appropriate to take a retrospective look at the people and the work that helped shape fruit fly research by ARS in Hawaii. In the spring of 2002, I asked research technician Hank Soboleski, an accomplished writer in his spare time, to document, in laypersons' language, the Agricultural Research Service's over eighty-year-old fruit fly research effort in Hawaii. Hank enthusiastically agreed and in his spare time, work commenced on what would soon become known as the "History Project."

This "history" would be by necessity an abbreviated retrospective that would include notable events, scientific discoveries, and the interesting anecdotal stories of ARS employees past and present. Project research would consist of interviews of ARS employees, both in Hawaii and outside who helped impact fruit fly research, and a review of scientific and other documentation, such as past and current scientific papers and historical information available such as the "Quarterly Reports of Fruit Fly Investigations" on file at the ARS Manoa, Oahu Laboratory.

We hope that this work will be considered in the spirit from which it originated - an honest effort to document and celebrate the past accomplishments of researchers and staff who worked on fruit flies. We also hope that this document will inspire current fruit fly researchers worldwide and ARS staff working on fruit flies who may not realize that they are part of an important lineage.

Dr. Eric Jang, Research Leader
Tropical Plant Pest Research Unit
Hilo, Hawaii
April 2005

Introduction

There are more than 1,000 known species of fruit flies worldwide, some of which have become major crop pests and are a threat to important agriculture regions in the United States, in states such as Florida, California, and Texas, and in other agriculture areas in many parts of the world. Today, tephritid fruit flies represent one of the most destructive pests worldwide, impacting fruit and vegetable production in developed and underdeveloped countries, increasing the worldwide use of pesticides, creating severe quarantine restrictions which impact world trade of agricultural products, and spreading throughout the world at an alarming rate.

To combat these destructive pests, many millions of dollars have been spent over the years to discover, invent, and develop various control and eradication technologies, with scientific research continuing throughout the world today.

The history of fruit fly research by the ARS and its predecessor agencies in Hawaii (most often in cooperation with other ARS locations, or other government and scientific entities), demonstrates that ARS-Hawaii has made important contributions in the battle against fruit flies. And, the technologies developed in Hawaii have for many years been transferred to the mainland United States and elsewhere across the globe to be used wherever fruit flies pose a threat to agriculture. Seminal research from ARS in Hawaii that has lead to the successful control of fruit flies in many part of the world include studies on fruit fly lures and attractants, the male annihilation technique (MAT), mass-rearing of fruit flies, application of the sterile insect technique (SIT) for use with fruit flies and biological control of fruit flies.

Chapter One

The Introduction and Establishment of Fruit Flies in Hawaii

Since 1895, four economically important tephritid fruit fly species have been accidentally introduced and established in the Hawaiian Islands. They are the melon fly (*Bactrocera cucurbitae*), the Mediterranean fruit fly (medfly, (*Ceratitis capitata*), the oriental fruit fly (*B. dorsalis*), and the Malaysian (solanceous) fruit fly (*B. latifrons*).

The melon fly, originating in South-East Asia, came to Hawaii by way of Japan in 1895. ARS photo.

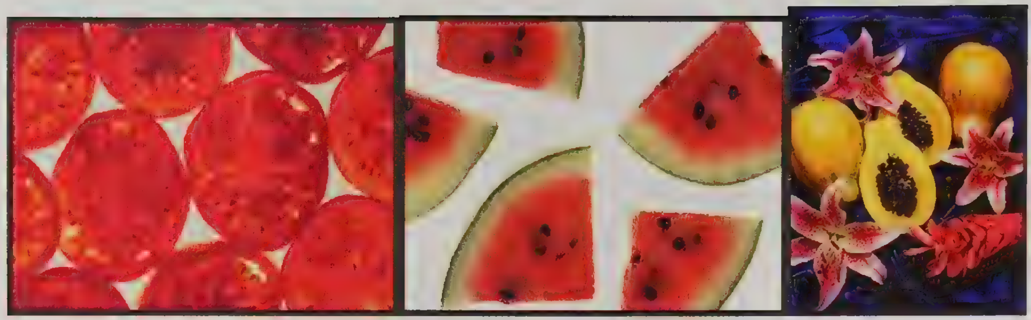
Mediterranean Fruit Fly, *Ceratitis capitata* native to West Africa, spread to Hawaii by 1907. ARS photo.

Indigenous to South East Asia, the oriental fruit fly was introduced into Hawaii in 1946 by way of military air transport from Saipan.

And, the fourth fruit fly pest to find its way to Hawaii, the Malaysian fruit fly, was introduced in 1983. Its origin is traced to South and South East Asia.


Malaysian Fruit Fly. ARS photo.

These winged insect pests attack over 200 different types hosts – fruits, vegetables, nuts, and flowers – that are grown in Hawaii: citrus, mangoes, guavas, peaches, apricots, coffee, breadfruit, bananas, papayas, cantaloupes, tomatoes, cucumbers, and other cucurbits to name a few, causing costly damage.



Tomatoes, watermelon, papaya and many other fruits, vegetables, nuts, and flowers are attacked by fruit flies in Hawaii. ARS photos.

Damage initially occurs when a female fruit fly punctures the exposed surface of a host with its ovipositor and lays its eggs inside, and destruction continues when fruit fly larvae develop from these eggs to consume and thereby ruin the host.

Mediterranean Fruit Fly, Pupa, Larva, and Eggs. ARS photo.

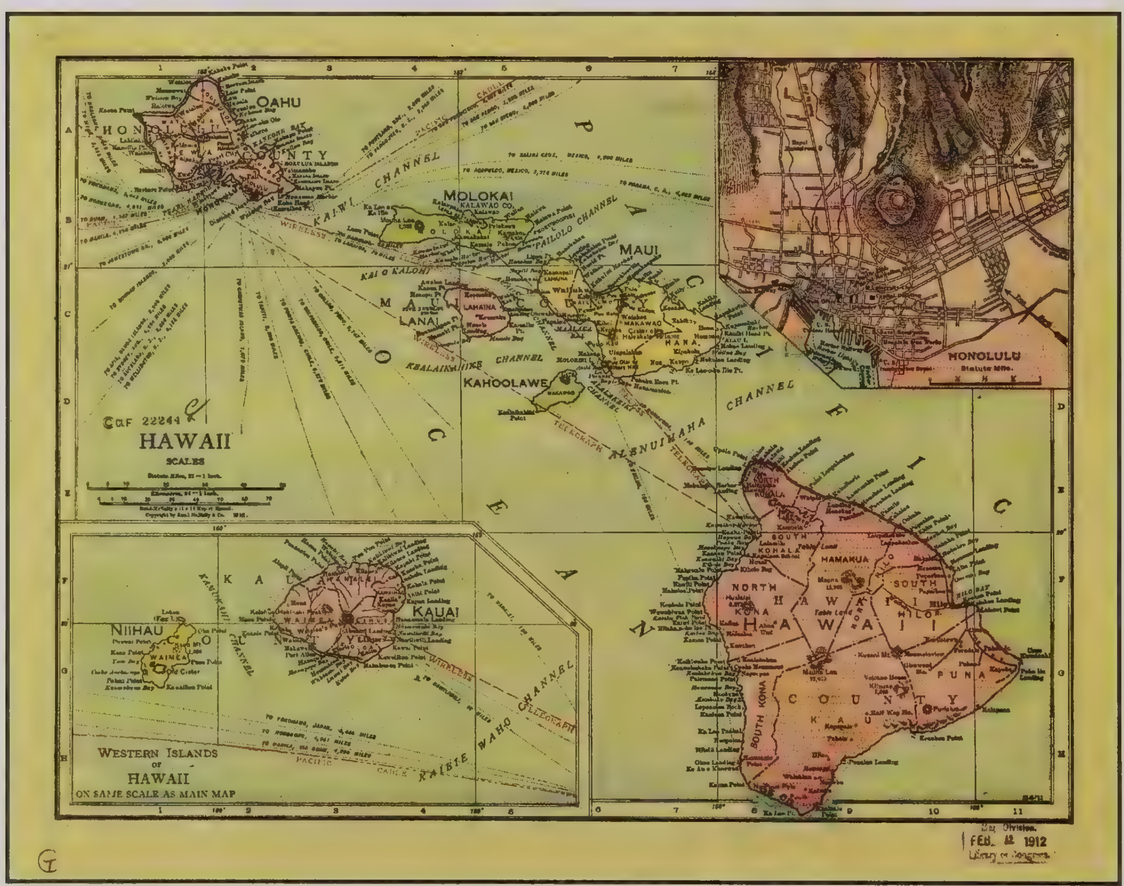
Fruit Fly Larvae infesting a Surinam cherry. ARS photo.

Fruit Fly larvae at their destructive work. ARS photo.

Chapter Two

Research on Biology and Biological Control of Fruit Flies

In 1912, five years after the introduction of the Mediterranean fruit fly into Hawaii, the Bureau of Entomology of the United States Department of Agriculture, the original agency-predecessor of ARS in Hawaii, opened a laboratory in Honolulu, which was equipped and staffed for the purpose of conducting fruit fly investigations, and was located within the Territorial Board of Agriculture and Forestry (the forerunner of the State of Hawaii Department of Agriculture) facility at 1428 South King Street.



Map of the Territory of Hawaii, 1912, the year the agency-predecessor of ARS, the Bureau of Entomology of the USDA, first began fruit fly research in Hawaii. Library of Congress map.

Entomologists from the Bureau, the Territorial Board, and the Hawaii Experiment Station then joined forces to combat the Mediterranean fruit fly, which threatened Hawaiian agriculture and also posed a danger to mainland United States agriculture, should it somehow be carried from Hawaii to the mainland U. S.

Fruit fly biology and life history investigations were conducted early on that uncovered many interesting and useful facts about fruit flies. For instance, research showed that melon flies could live for over one year (one female lived the longest – 431 days) and could produce as many as 10 generations per year. They could also fly or be carried on the wind for at least as far as 45 miles, and could live at elevations as high as 6,500 feet above sea level.

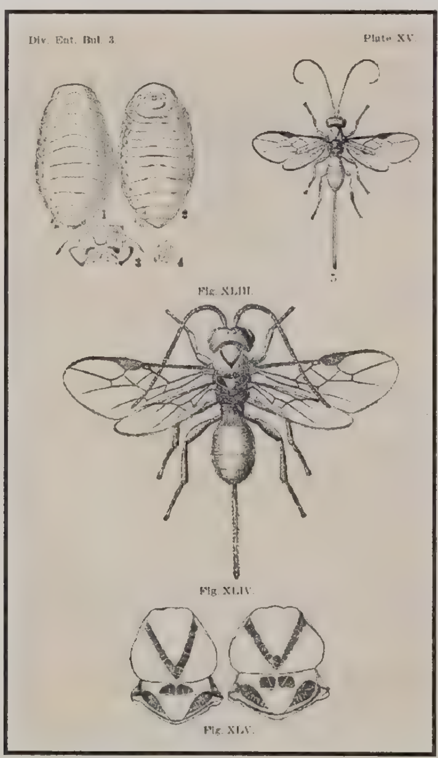
Other early work included investigating the life cycles of fruit flies, surveys of hosts infested by fruit flies, and testing of various control measures against fruit flies.

Left to right: Melon fruit fly, and its eggs, larvae, and pupae. Life cycle: After adult flies emerge from the puparium, the females can cause damage to hosts. Adult females puncture hosts with their ovipositor and deposit eggs inside, where the eggs hatch within 24 to 48 hours (at 77 degrees F). In the larval stage, fruit fly larvae damage hosts by feeding and tunneling within them. Larvae then form a puparium from which adults develop. ARS photos.

Meanwhile, the battle against the fruit fly gained momentum when opiine wasps – fruit fly parasitoids that complete their larval development within the bodies of specific fruit fly hosts and eventually kill them – were collected in Africa during 1912 and 1913 by the famous Italian entomologist, Professor F. Silvestri, and were released in Hawaii.

This map shows the route of Professor Silvestri. From Bulletin No. 3, 1914, Territory of Hawaii, Board of Agriculture and Forestry.

Silvestri brought five species of fruit fly parasites to Hawaii, notably *B. tryoni*, at that time named *D. tryoni*, which became the most effective species that parasitizes the Mediterranean fruit fly.

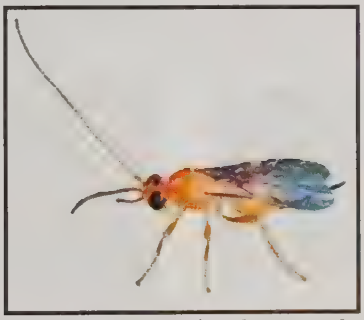


A Silvestri plate that shows *B. tryoni* at top right. From Bulletin No. 3, 1914, Territory of Hawaii, Board of Agriculture and Forestry.

Entomologists involved in the work included: Dr. E. A. Back of USDA (Dr. Back is the earliest USDA Hawaii employee-name uncovered in the history research), D. T. Fullaway of the Hawaii Experiment Station, and E. M. Ehrhorn, J. C. Bridwell, and W. M. Giffard of the Territorial Board of Agriculture and Forestry.

Once these wasps had multiplied to sufficient numbers in nature, they became an effective biological control of the Mediterranean fruit fly. In fact, scientists estimated that the Mediterranean fruit fly population was cut in half following the establishment of Silvestri's opiine wasps in Hawaii.

These parasitic wasps were harmless to fruits, vegetables, nuts, and flowers, since they did not sting or eat these plants as did their hosts, the fruit fly. Instead, they stung and fed on fruit flies.



Fruit Fly Parasite – *P. fletcheri.* ARS photo.

This stinging and feeding process begins when a female wasp punctures a fruit fly egg or larva with its ovipositor and oviposits its eggs inside – each egg being about eight times smaller than a fruit fly egg.

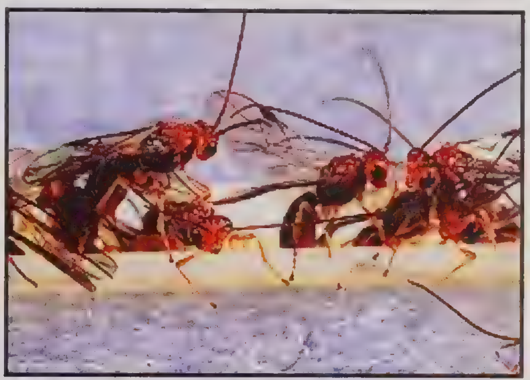
The eggs then hatch within the fruit fly egg or larva and develop to maturity in stages (egg, larva, pupa, and finally, a free-living adult wasp) within the body of the similarly developing fruit fly. While the wasp is in the larval stage, it consumes the body of its fruit fly host as food and thus kills it. When the wasp's larval development is complete, a parasitic wasp emerges from the pupa, instead of a fruit fly.

Since Silvestri's original parasite releases in Hawaii, many more species of parasites have been released in Hawaii. In fact, between 1947 and 1952, the Hawaii Lab and cooperating agencies (Dr. Wallace Mitchell of the University of Hawaii played a significant role) released 32 natural enemies of the oriental fruit fly into Hawaii to suppress the oriental fruit fly population. Of these, *F. arisanus (formerly B. arisanus)*, *D. longicaudatus*, and *F. vandenboschi* became primarily responsible for a great reduction in the oriental fruit fly population. Fruit fly parasites currently found in Hawaii are *F. arisanus, F. vandenboschi, Diachasmimorpha longicaudata, D. tryoni, Psyttalia fletcheri*, *P. incisi*, and a few less effective parasitoids.

Colorful parasite montage provided by Dr. Ernie Harris of the Manoa Lab in Honolulu. ARS photos.

Today, large numbers of wild parasites in nature are responsible for limiting the size of the fruit fly population in Hawaii.

To cite one example, it's estimated that *F. arisanus*, which comprises 70% to 90% of the total Hawaiian fruit fly parasite population and is the principle parasitoid attacking the oriental fruit fly, parasitizes 50% to 75% of the oriental fruit flies found in wild guava, the primary host of the oriental fruit fly in Hawaii. *F. arisanus* is also the primary parasitoid attacking melon fruit flies.

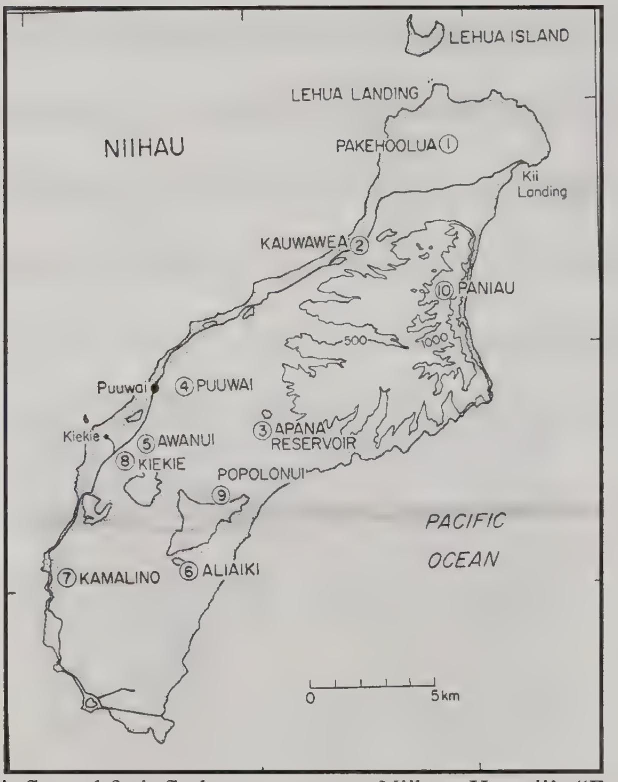


F. *arisanus* is Hawaii's most effective fruit fly parasite. ARS photo.

As Dr. Roger Vargas explains:
"Our field results suggest that although three different types of parasitoids (egg-pupal, larval-pupal, and pupal) are active against *C. capitata* and *B. dorsalis*, the egg-pupal parasitoid, *F. arisanus*, appears to have an insurmountable advantage in the parasitoid guild because it attacks host eggs close to the surface of fruits and apparently inhibits development of competing larval-pupal parasitoids that attack a later host stage often dispersed throughout the fruit (van den Bosch and Haramoto 1953). Furthermore, the original parasitoids (*D. tryoni*, *T. giffardianus*, and *D. giffardii*) brought to Hawaii for *C. capitata* control by Silvestri are now rare. Parasitoids introduced for *B. dorsalis* control during the late 1940s and early 1950s (i.e., *F. arisanus* and *D. longicaudata*) are now the major natural enemies of fruit flies in coffee. Finally, there appears to be little elevational effect (274–610 m) on the ecological range of *F. arisanus.* However, elevation did significantly affect the abundance of *F. arisanus* with respect to other parasitoids, most notably at low elevation."

From 1946 to 1976, host surveys were conducted throughout the islands from sea level to the tops of the volcanic mountains to determine the host range of these pests.

Drs. Roger Vargas, Nic Liquido, Ernest Harris, Tim Wong, and others surveyed many areas in Hawaii, and biological work in ongoing with Dr. Grant McQuate.



Dr. Vargas conducted fruit fly and fruit fly host surveys on Niihau, Hawaii's "Forbidden Island." Access to Niihau is restricted by its owners, Bruce and Keith Robinson. Vargas surveyed Niihau's fruit fly population in the early 1990s with the assistance of technician Hank. Soboleski. Above map shows trap sites circled 1 through 10. R. Vargas map.

Dr. Grant McQuate of Hilo continues the study of fruit fly biology by seeking to improve understanding of infestation risks to quality and export potential of tropical crops through documentation of natural infestation levels, and research on infestation biology of internal pests, and improving knowledge of host ranges of tephritid fruit flies by developing data bases of host plants reported in the literature, together with documented infestation levels.

Entomologist Dr. Ernie Harris of the Manoa Lab has this to say regarding the study of the biology of fruit flies and their parasites: “The basic biology of parasites requires investigation of fruit flies and parasitoids to understand how they relate to each other in the use of the resources found in the areas they share together. Do not expect them to behave always according to what the written record says. One must be open minded and insightful enough to design your approach to your investigation so you can see what happens regardless of whether or not is like or unlike what has been written before. Remember that the tools we use to study the population ecology of insects is male biased because of the relative efficiency of the male lures used to study tephritid fruit flies. Perhaps our instincts would be more sensitive if we did not use male lures or at least use some other tools so we do not reply to heavily on the male lures or be so heavily influenced by the data we collect with male lures. We have only one tool that tells us what the choices of tephritid fruit fly females are, and that is fruit samples. That is the only tool we have which inevitably speaks for tephritid fruit fly females. It tells us where they put their young for the next generation and what habitat they prefer.”

Chapter Three

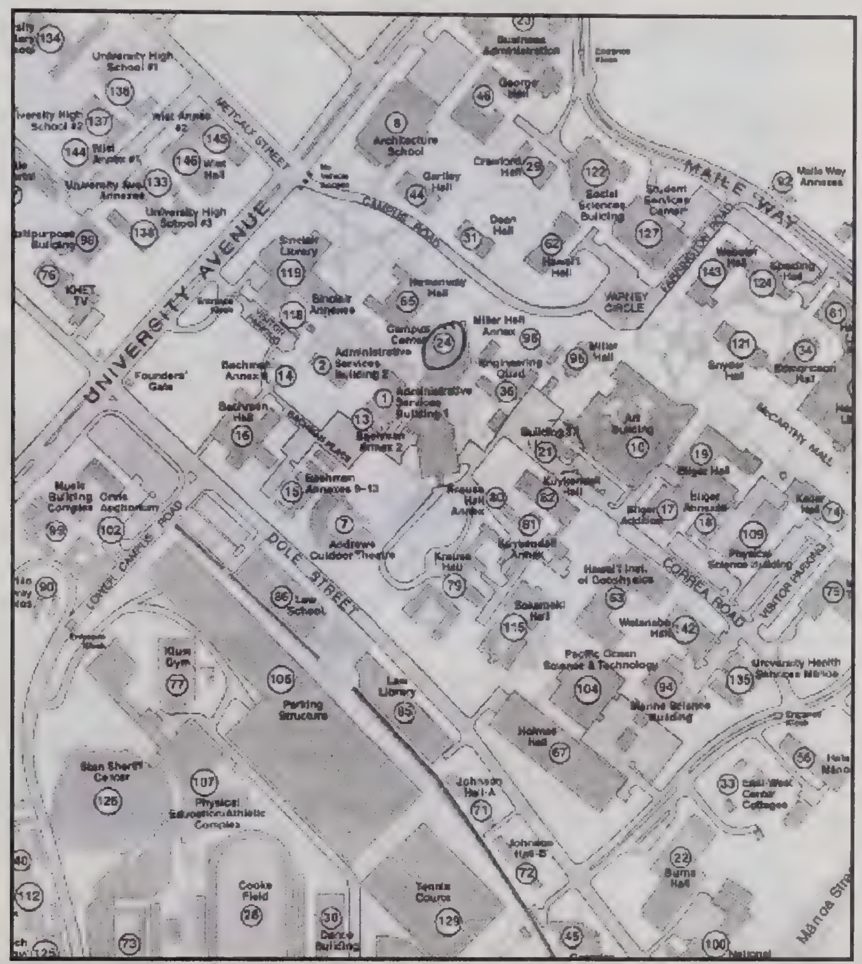
The Beginnings and the Growth of Commodities Treatments and Plant Quarantine in Hawaii

Work with parasitoids, continued research into fruit fly biology, life history investigations, and the search for better biological and chemical controls of fruit flies went forward at a steady level at the Hawaii Laboratory until 1929, when a costly outbreak of Mediterranean fruit fly in Florida prompted the Bureau of Entomology and Plant Quarantine to expand and speed-up the intensity of its fruit fly research program in Hawaii.

An outbreak of Mediterranean fruit fly in Florida in 1929 caused an expansion and speed-up of fruit fly research in Hawaii. University of Florida map.

As consequence of this outbreak, Bureau headquarters in Washington sent additional entomologists and chemists to augment the Hawaii Laboratory during the following year, 1930, and its downtown Honolulu laboratory was moved in 1931 to a larger facility that

was constructed on the campus of the University of Hawaii at Manoa, now the location of the Campus Center.



In 1931, the Hawaii Laboratory moved from its downtown Honolulu location to the University of Hawaii campus on a site that is now occupied by the university's Campus Center (24-circled) as shown on this recent University of Hawaii map.

Two pictures of the USDA Hawaii Lab on the University of Hawaii Manoa campus as photographed during the early 1960s. The Hawaii Laboratory was located at this University of Hawaii site from 1931 until 1973. Afterwards, the building was torn down to make room for the university's Campus Center. E Harris photos.

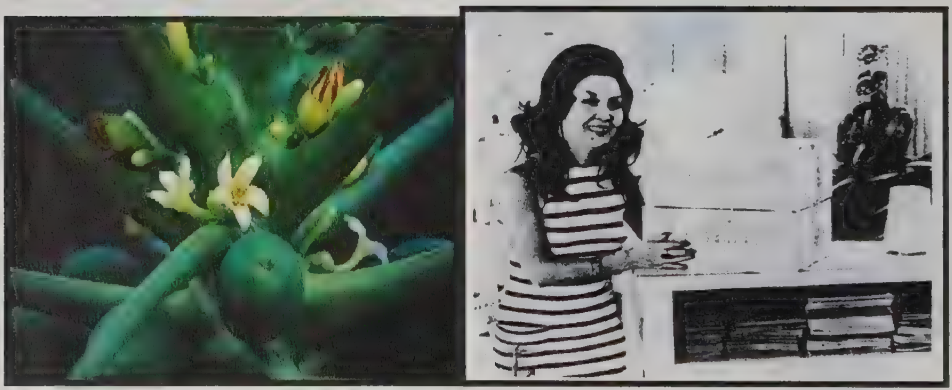
In the 1930s, work focusing on commodity treatments was initiated and a vapor heat commodity treatment was developed to kill infestations of fruit flies in produce.

But many commodities could not tolerate the relatively high heat and duration of this treatment –110 degrees F for 17 hours.

In the process of discovering better methods of treating commodities other than the use of vapor heat, over 200 liquid chemicals were tested and evaluated beginning in 1949.

This painstaking research eventually led to the discovery of an effective disinfestation agent, ethylene dibromide (EDB), which opened the export market for Hawaii's papaya industry.

Hawaii papaya orchard and Big Island woman with freshly harvested papaya. ARS photos.



Close up of young papaya fruit and flowers, and circa 1970s, a woman at Honolulu International Airport with boxed papayas ready to be shipped after fumigation with EDB. ARS photos.

Research chemist Stanley Seo of the Honolulu Lab did pioneering work in the field of post-harvest disinfestation. His research included work with vapor heat, ethylene dibromide, and methyl bromide for use in disinfestation. ARS photo.

EDB served Hawaii agricultural very well for many years until 1984, when it was banned as a fumigant by the Environmental Protection Agency due to its toxic properties, which included harm to the ozone layer of the Earth's atmosphere.

ARS consequently placed a high priority on finding alternatives to EDB, which led to a greatly increased level of commodities treatment research.

Hawaii Lab technician closing door to experimental fumigation chamber that was used to test dosages and tolerances required for disinsecting various kinds of produce. ARS photo, circa early 1970s.

During the 1980s and 1990s, Hawaii-based scientists Drs. Jack Armstrong, Eric Jang, Harvey Chan, and Research Leader H. Melvin Couey comprised the team of researchers whose urgently required work ultimately led to the introduction of commodity treatment disinfestation alternatives such as the "double dip" and the "hot-forced-air treatment" for papayas and other commodities.

Youthful Dr. Eric Jang at work in the 1980s. E Jang photo.

Drs.Chan and Couey were research food technologists and plant physiologists respectively, who provided much needed research skills to the largely entomology group. Their insight on non-entomology research needs in the post-harvest commodity group and their research expertise significantly helped save the papaya industry at a time when the loss of EDB could have been a disaster to the industry. In fact, Couey invented "double hot water dip" for disinfestations of fruit flies in papaya and Chan's work led to significant improvements in this technique.

Drs. Chan and Jang were the first to look at the concept of thermal death kinetics of insects and apply it to susceptibility of fruit fly immature stages to heat treatments. Dr.

Chan also initiated the lab's first research on product quality and "value-added" products, such as aseptic processing of excess papaya production.

Dr. Couey also brought his expertise on plant physiology to look at post-harvest disease issues such as fungal rots to increase the shelf life of papayas. Research technicians Kate Nishijima, Tony Nakamura, and Ed Linse worked with Dr. Couey on many of these projects.

Dr. Jack Armstrong, Dr. Melvin Couey, and unidentified man in the field on Big Island. E Jang photo.

Plant pathologist Kate Nishijima at her microscope at the Hilo Lab, where she works in the Post harvest Tropical Commodities Research Unit. ARS photo.

Dr Harvey Chan. Eric Jang photo.

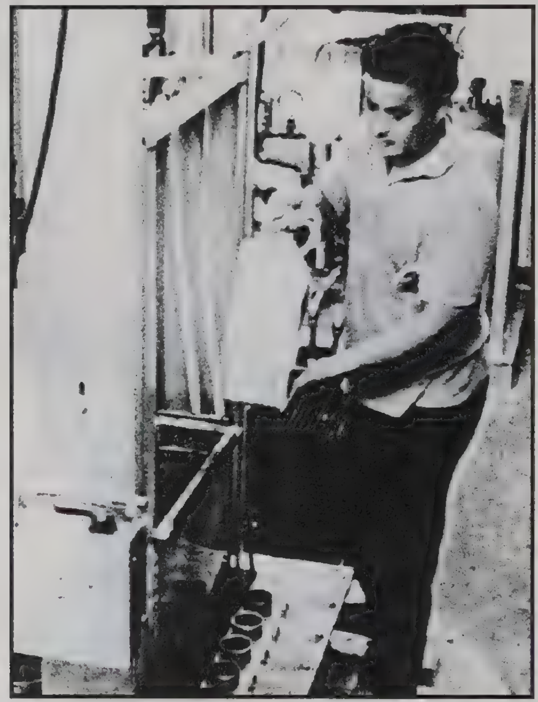
Technicians Vinnie Shishido and Sandra Silva caging banana bunch in commodities treatment field test. J. Armstrong photo.

Left photo: Bill Pfeil left, the manager of Hawaii Papaya Growers, and ARS entomologist and Research Leader Dr. Jack Armstrong assess the quality of papayas after hot-forced-air treatment. Photo right: Entomologist and Research Leader Dr. Jack Armstrong, left, shown here examining papayas with Dole Food Hawaii president Jerry Vriesenga. Dr. Armstrong currently heads the Postharvest Tropical Commodities Research Unit of the ARS in Hawaii. ARS photos.

Quarantine measures were also necessary, and these were first implemented during the 1930s at Hawaii's ports of entry and exit. At its airports, passengers' baggage was inspected to prevent the inadvertent spread of fruit flies to the mainland United States and foreign countries. Infested produce, or produce not having undergone proper fumigation, was impounded or destroyed.

These pictures taken at Honolulu International Airport in early 1970s show plant quarantine inspector on left impounding papaya that could have spread fruit flies to the mainland U. S. On right are quarantine personnel inspecting passengers' baggage to prevent the spread of fruit flies to the mainland. ARS photos.

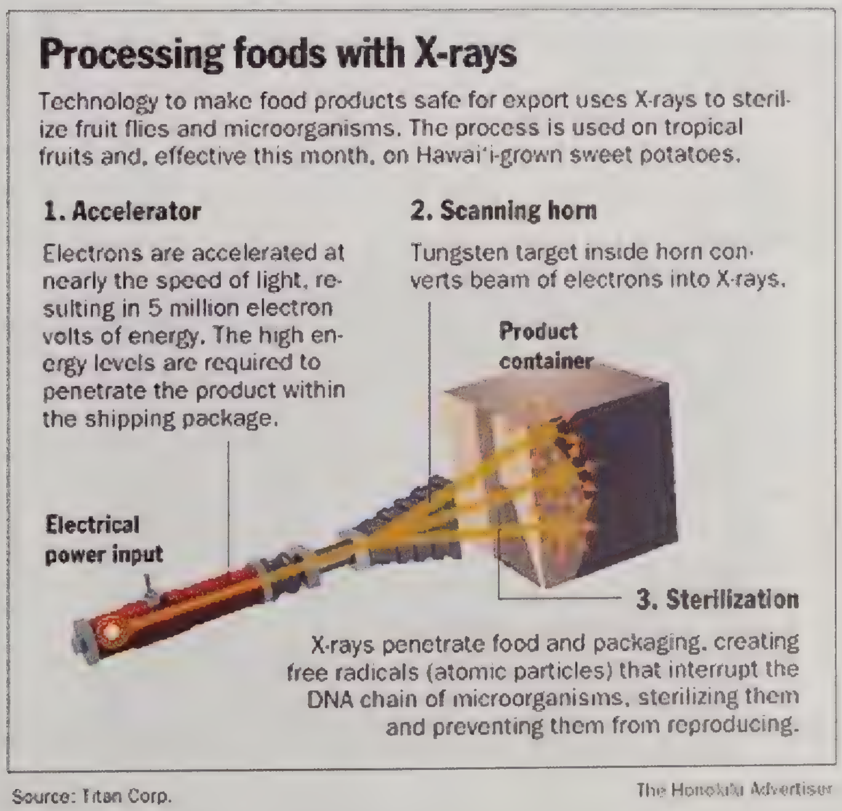
The use of gamma irradiation as a disinfectant began at the Honolulu Laboratory in 1954. At first, a radioactive Cobalt source of 1 curie was used. Later, in 1957, a 415-curie gamma irradiator was acquired, and minimum doses of radiation required to destroy fruit flies in many kinds of fruits and vegetables were established.



Circa early 1970s is technician Clifford Lee loading mangoes into the irradiator at the Honolulu Lab. ARS photo.

Entomologist Dr. Peter Follett of the Hilo Lab has recently worked to lower the generic dose of radiation required to disinfect oriental, Mediterranean, and melon fruit flies in fruits and vegetables. ARS photo.

Irradiation quarantine treatment doses of 250, 225 and 210 Gy are currently approved by USDA-APHIS for control of oriental fruit fly, Mediterranean fruit fly and melon fly, respectively. Dr. Follett's irradiation studies demonstrated that these doses could be reduced. Dr. Follett's research supports a generic dose of 150 Gy for tephritid fruit flies, which was proposed first by the International Consultative Group on Food Irradiation in 1991. Lowering the irradiation dose for these quarantine insects would reduce costs and increase capacity for treatment facilities, and minimize quality problems in radiation-sensitive fruit and vegetables. USDA-APHIS approved the proposal of a generic 150 Gy treatment for tephritid fruit flies and is preparing a proposed rule. Publication of the final rule approving the generic treatment will expand trade in irradiated fruit and vegetables worldwide and promote irradiation technology.

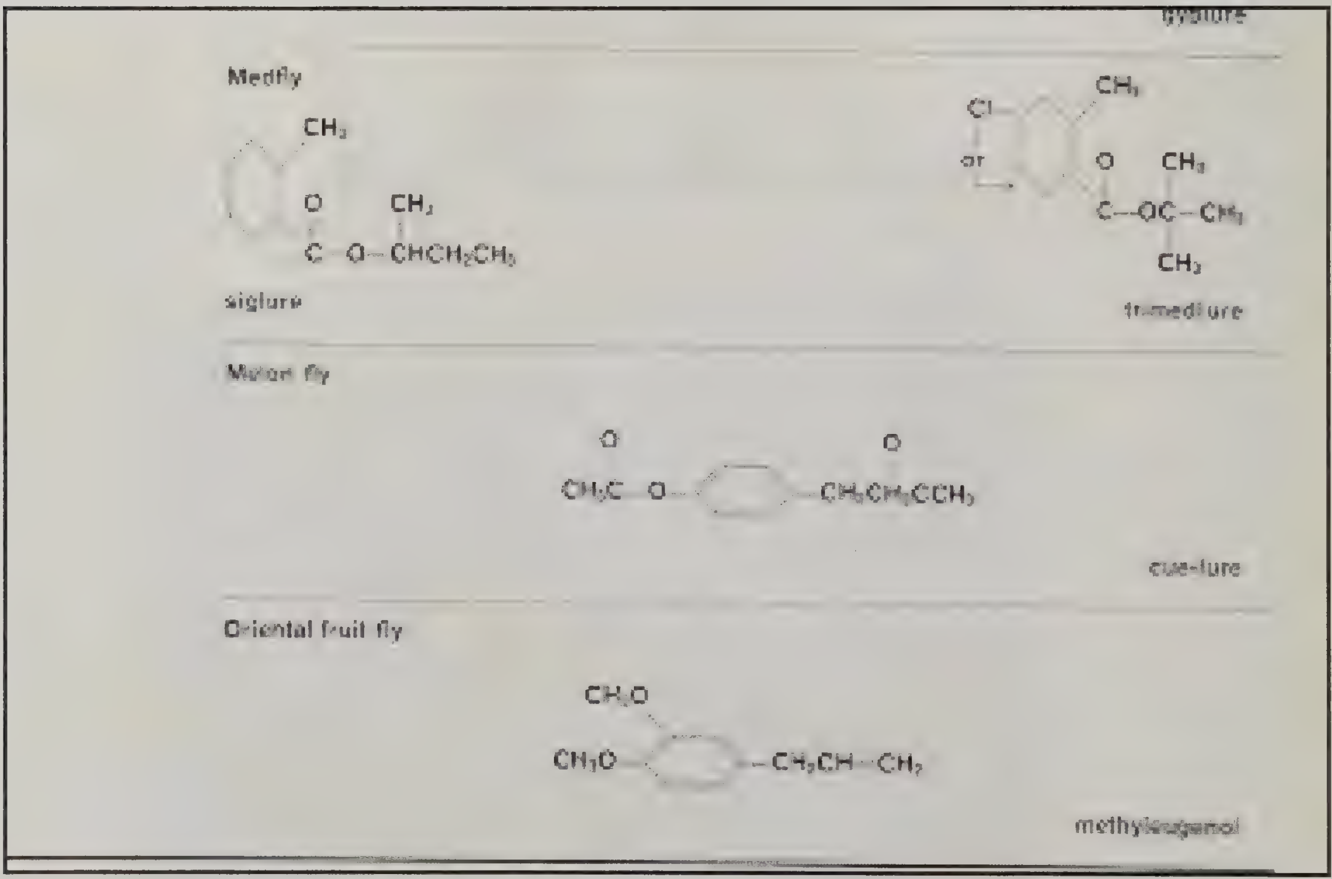


X-ray process for SureBeam Irradiation. *The Honolulu Advertiser* picture provided by J. Armstrong.

Chapter Four

The History of Fruit Fly Attractant Research in Hawaii

The fruit fly lures that ARS in Hawaii has played a key role in discovering, developing, or implementing are trimedlure, cue-lure, methyl eugenol, melolure, ceralure, and, latilure. Of these, trimedlure, methyl eugenol, latilure and cue-lure are routinely used to detect male Mediterranean, oriental, solanaceous and melon flies.



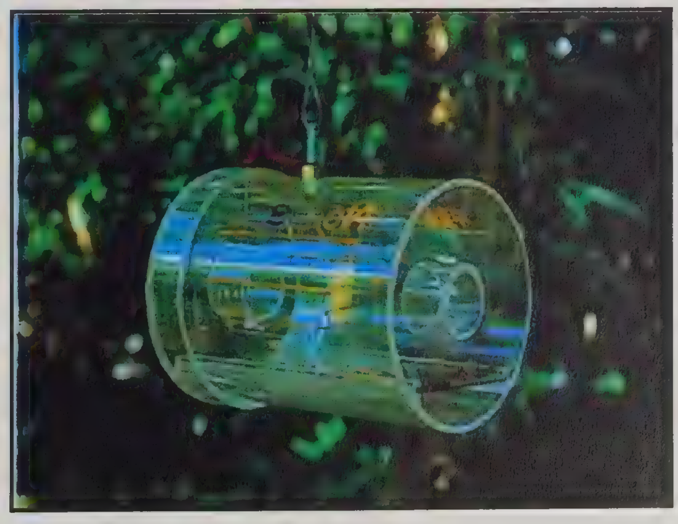
The ARS Laboratory in Hawaii, in cooperation with the ARS Beltsville, Maryland Lab, played an essential role in discovering and developing methyl eugenol, cue-lure, and trimedlure. M Beroza document.

In the early days of ARS's research efforts in Hawaii, hosts such as bananas, guava, and papaya were used to lure both sexes of fruit flies into traps or locations where they could be simply killed, or counted as is the case in survey work.

But stronger fruit fly attractants were needed to lure these flies to destruction more efficiently and in greater numbers, and there was also a need to be able to detect and survey fruit fly populations more precisely that better attractants could fulfill.

Systematic fruit fly attractant research in Hawaii was first carried out by Dr. Walter Carter's (affectionately known as "Sir Walter" for his refined mannerisms) Chemical Control Project Group in the 1940s.

Leading this group was Loren F. Steiner, who not only did major pioneering work in the field of attractants, particularly methyl eugenol with L. D. Christianson, but also led the way in the development of fruit fly suppression tactics such as sterile male releases, protein bait sprays, and male annihilation – and he invented the well-known and still-used Steiner trap.

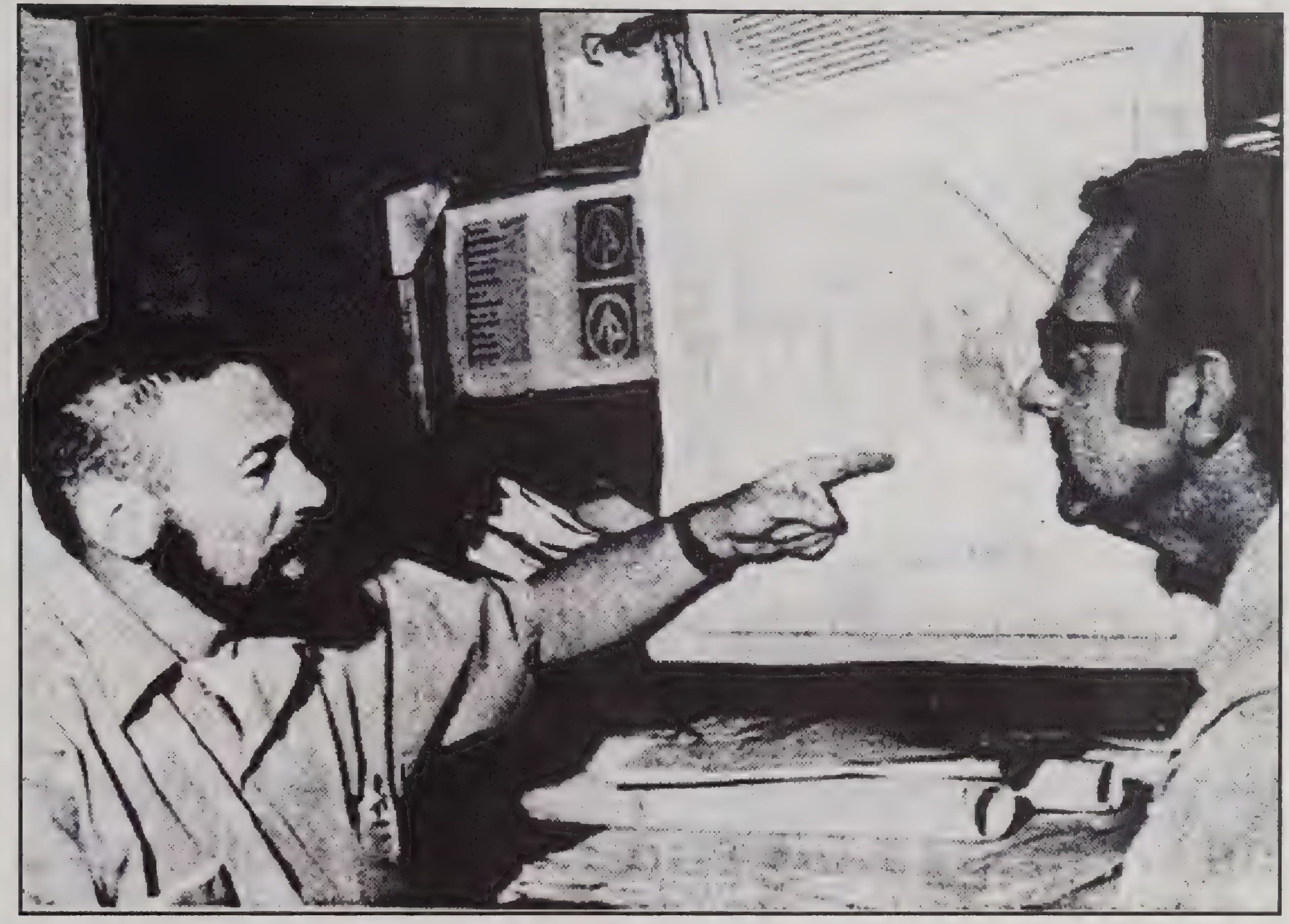


ARS Hawaii scientist Loren Steiner was a great pioneer in the field of fruit fly attractants, and along the way, he invented the Steiner trap, still used today. ARS photo.

Working under Steiner during the 1940s was Paul L. Gow, a chemist now known as the "Father of Attractants," since he was the first scientist to scientifically investigate attractants. Gow began simply by studying host fruits as attractants, and later developed the first protein-based attractant for both male and female fruit flies. It was named "Standard Lure" and it contained yeast, vinegar to maintain a preferred PH level, sugar, and water. Paul Gow also led research to discover what compounds within the protein-base attracted fruit flies. Gow's other work incorporated original research on a perfume base attractant for the Mediterranean fruit fly.

But, the very first Mediterranean fruit fly male lure – and the first male lure for any species of fruit fly – was discovered in Australia in 1907 and was later investigated by ARS Hawaii entomologist Roy Cunningham in the 1980s.

The first male fruit fly lure was discovered "by chance" in Australia in 1907. CIA map.



In the 1980s, ARS Hawaii entomologist Dr. Roy Cunningham left, shown here with Dr. Peter H. van Schaik of ARS Albany, California, reinvestigated the first male fruit fly lure.
ARS photo.

In 1907, an Australian woman by the name of Mrs. Devenish used kerosene as an ant barrier to protect a batch of jam she'd cooked, and when large numbers of flies were then attracted to the ant barrier and the jam, Mrs. Devenish's husband noted that the flies were medflies, and he also somehow determined that these flies were attracted to the kerosene and not the jam.

Excited by the prospects of killing more of these flies in his fruit orchard, Mr. Devenish set pans of kerosene in the orchard and killed so many flies of all sorts that Australia soon passed regulations that enforced the use of kerosene in fruit orchards.

Unfortunately, this amazing story came to an unsuccessful conclusion when it was learned that in 1913 that less than 1% of the flies being killed were damage-producing female medflies, and the Australian program was consequently abandoned.

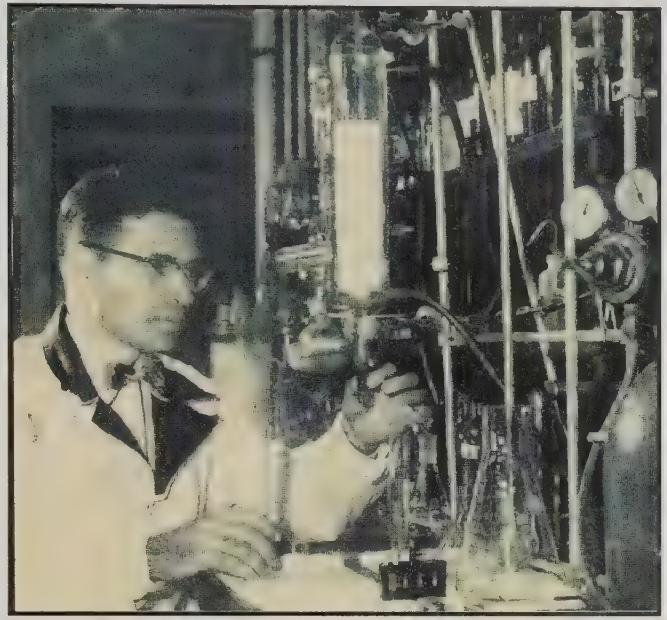
Surprisingly, however, practically no work was done for the following 30 or so years to identify the active components that made Devenish's kerosene a powerful attractant to flies. And oddly, when kerosene was finally analyzed for attractants in the 1940s, only a few slightly attractive compounds were discovered.

In the 1980s, when Dr. Roy Cunningham picked up on this intriguing research and tested several commercial kerosenes in Hilo, Hawaii, he learned that they were only 1% as attractive as the best male lures available. Why? Perhaps, there was something unique in the mix of the turn-of-the-century Australian kerosene that attracted great numbers of flies. But, no samples of the Devenish's kerosene existed by the time Cunningham made his tests, and we'll probably now never know exactly what made Mr. and Mrs. Devenish's kerosene so good at attracting medflies, and all sorts of other flies.

In 1957, a second invasion of Mediterranean fruit flies into Florida prompted an intensive cooperative effort between chemist Dr. Morton Beroza, head of the Synthesis Investigations Group at Beltsville, Maryland, and scientists and technicians at the Hawaii Lab to find a substitute for angelica seed oil (extracted from a genus of herbs of the carrot family, and then the lure of choice for medfly), which was highly attractive to male medflies, and was produced in Holland, but was in short supply while being used in Florida to eradicate the medfly.

Beroza and his chemists would synthesize potential chemical compounds, and then send them by airmail to the Hawaii Lab for testing and evaluation. In close collaboration

with scientists in Hawaii, Beroza and his group would try to improve attraction and extend duration of attraction by modifying the chemical structure of the compounds.



ARS Hall of Fame chemist Dr. Morton Beroza working in his lab in 1955. Morton Beroza photo.

Morton Beroza was inducted into the ARS Hall of Fame in 1997 because of his international reputation for discovering ingenious and inventive tools for controlling insect pests safely within their ecological domain. He also developed many environmentally compatible insect control strategies using insect lures, attractants, repellents, and pheromones. Furthermore, Beroza invented analytical techniques and apparatus now used by chemists worldwide. He worked as a chief of ARS's Organic Chemicals Synthesis Laboratory before retiring.

Morton Beroza at his induction into the ARS Hall of Fame, 1997. Left, Dr. Edward B. Knipling. Right, Dr. Phyllis E. Johnson. Morton Beroza photo.

AWARD CITATION

For invaluable contributions to the successful Mediterranean fruit fly eradication campaign, in Florida, by developing effective lures to delimit the distribution of the pest and measure results of eradication treatments.

RECIPIENTS OF AWARD

Entomology Research Division

Pesticide Chemicals Research Branch

Mr. W. F. Berthel*
Dr. Morton Beroza
Mr. S. I. Gertler
Mr. Nathan Green
Mr. S. A. Hall
Mr. R. W. Ihndris

Fruit and Vegetable Insects Research Branch

Mr. L. D. Christenson
Mr. Gilbert J. Farias
Mr. Paul Gow**
Mr. Irving Keiser
Mr. R. Kinoshita***
Dr. W. C. Mitchell
Miss Doris Miyashita
Mr. Suzumo Nakagawa
Mr. Kiichi Ohinata
Mr. L. F. Steiner
Mr. Tadao Urago
Mr. Teichi Yamada

* Now stationed with Plant Pest Control Division at Gulfport, Mississippi
** Deceased
*** Left service May 31, 1958

PRESENTATION

of the

SUPERIOR SERVICE UNIT AWARD

to the

PESTICIDE CHEMICALS RESEARCH BRANCH

and the

FRUIT AND VEGETABLE INSECTS

RESEARCH BRANCH

of the

ENTOMOLOGY RESEARCH DIVISION

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

December 16, 1959

2:00 p.m.

Agriculture Research Center

Beltsville, Maryland

Unit Citation Award for Eradicating Medfly from Florida in 1957. Note names of Hawaii Lab scientists and technicians on left in the Fruit and Vegetable Insects Research Branch section. Morton Beroza.

Program for Award Presentation

Dr. E. F. Knipling, Presiding

Introductory Remarks - Dr. E. F. Knipling, Director, Entomology Research Division

Chemical Research on Insect Attractants - Dr. Morton Beroza, Head, Synthesis Section, Pesticide Chemicals Research Branch

Testing of Lures and Traps in Laboratory and Field - L. D. Christenson, Head, Subtropical Fruit Insects Section, Fruit and Vegetable Insects Research Branch

Presentation of Award and Certificates - Dr. Byron T. Shaw, Administrator, Agricultural Research Service

Concluding Remarks - Dr. T. C. Byerly, Deputy Administrator, Farm Research, ARS

Refreshments

EXHIBIT - Insect Lures, Traps, Photographs

OPEN HOUSE - Pesticide Chemicals Research Branch

History of Research

Finding the Mediterranean fruit fly (or medfly) in Florida in April 1956 was just cause for alarm. This highly injurious insect had to be eradicated to protect our huge fruit and citrus industry. A good medfly lure was vitally needed for use in traps to locate the infested areas and also to measure the progress of eradication.

Fortunately only one month previously a potent medfly lure, angelica seed oil, had been discovered at the Honolulu Fruit Fly laboratory. But, as the world's supply of the oil was practically exhausted before the end of the year, another lure was needed to prevent the eradication program from bogging down. The synthesis group of the Pesticide Chemicals Research staff came to the rescue with a synthetic product that was pressed into commercial production in record time. During the course of this production a better lure was found and production was switched to it. Such subtle differences as the spatial configuration of the molecule were shown to be important and a method of synthesizing the more potent form was devised.

In November 1957 the last medfly was found. More than 10 million dollars had been expended to eliminate this species from almost 1 million infested acres.

The Division's lure research program has continued. Improved lures are now available to detect any incipient infestation of the medfly, melon fly and oriental fruit fly. Some of the lures are so powerful that they are being considered as a means of direct control or eradication of these important pests.

This research marks a beginning, not an end. We need lures for many more destructive species that pose a threat to our agriculture.

(Con't) Unit Citation Award for Eradicating Medfly from Florida in 1957. Morton Beroza.

Beltsville chemists, 1959: Nathan Green on left helped invent trimedlure. Ben Alexander on far right invented cue-lure with Morton Beroza. Morton Beroza photos.

One of Beroza's chemists, Samuel I. Gertler, was successful in synthesizing a highly attractive medfly lure in 1957, which Beroza named Siglure, based on Gertler's initials – SIG. Analytical methodology was devised to assure delivery of a high quality product by commercial producers of Siglure. With Siglure available, Hawaii's Loren Steiner, who headed the eradication program, eradicated the medfly from Florida by the end of 1957.

Beltsville chemist Samuel I. Gertler, the inventor of Siglure, receiving award, 1961. Morton Beroza photo.

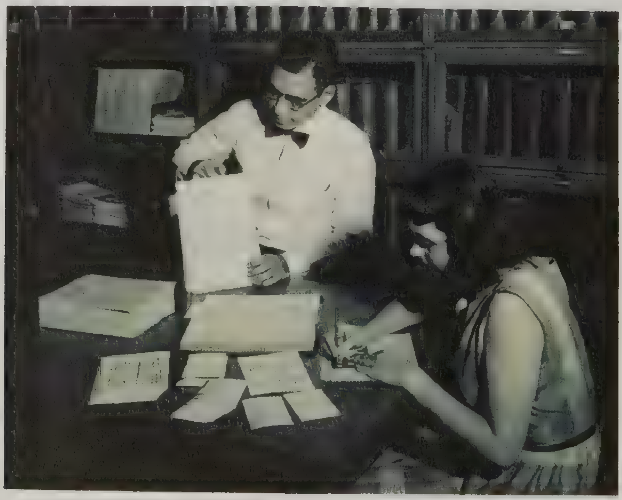
Siglure - $C_{12}H_{20}O_2$

Work continued under Morton Beroza's direction at Beltsville to find an even better attractant. He found one chemical (similar to Siglure) that W. F. Barthel tried to make before he was transferred about a year earlier to the Gulfport, Mississippi lab. It showed some attraction for the medfly, even though it was impure. Beroza gave Nathan Green directions to prepare the desired compound, but he likewise failed. He was then asked to retry the synthesis, but this time Beroza watched the preparation. The invention of trimedlure followed and is here described by Morton Beroza:

"While I was reviewing his (Green's) retrial, I noted two immiscible liquid layers in the reaction flask, and immediately realized why Barthel and Green were unsuccessful. I had Green add enough dioxane to form a single homogeneous layer of the reacting liquids. Dioxane is an unreactive liquid that dissolves polar and nonpolar liquids (like water and oil). Homogeneity allowed the chemicals to react, and the desired compound was obtained in high yield."

Trimedlure - $C_{12}H_{21}ClO_2$

Evaluated and put to the test in Hawaii, trimedlure proved to be the best male medfly attractant.



Dr. Morton Beroza at work with his secretary at Beltsville. Md., 1950s. M Beroza photo.

Oriental and Mediterranean Fruit Flies and Melon Fly

Honolulu, Hawaii—L. D. Christenson, formerly in charge, L. F. Steiner, now in charge, D. H. Miyashita, K. Ohinata, W. C. Mitchell, Shizuko Mitchell, I. Keiser, and P. Gow[8]

In laboratory screening tests, Gow's olfactometer (9) was stocked with 25,000 to 150,000 insects. The olfactometer (fig. 1) is a room-sized cage, 9 feet square and 8 feet high, equipped with a horizontally mounted wheel, which is slowly rotated to eliminate any positional advantage. Suspended from the wheel are invaginated glass traps, which contain the test materials, usually in 0.1-percent aqueous emulsions. Four candidate lures were tested simultaneously and each was replicated three times. The cage was located outdoors to approximate natural conditions, and breezes prevented accumulation of undesirable odors. Since supplies of food and water were available at all times, a candidate lure had to prove itself in competition with these essentials. The candidate lures were usually screened against the oriental and Mediterranean fruit flies and melon flies at the same time.

The materials were classified according to their attractancy index, which was obtained by dividing the number of insects caught with the candidate lure by the number caught with plain water.

	Attractancy index for—	
Class	*Males*	*Females*
1	Less than 11	Less than 6.
2	From 11 to 50	From 6 to 50.
3	Greater than 50	Greater than 50.

Supplemental laboratory tests, which were made before a lure was tested in the field, were employed

[8] Deceased Dec. 12, 1954.

FIGURE 1.—Screening potential oriental fruit fly attractants in the olfactometer.

Hawaii Lab technician Doris Miyashita evaluated about 6,000 chemicals and compounds sent to her by Dr. Beroza and his chemists. It was she who made the actual discovery of trimedlure. In the Manoa Lab today can still be found Doris's filing cabinet filled with 3x6 cards identifying the many compounds she evaluated. Communications between Hawaii and Beltsville were made by telegraph and airmail in those days. In the

pictures above and below, we see Doris screening potential attractants in an olfactometer.

M Beroza photos.

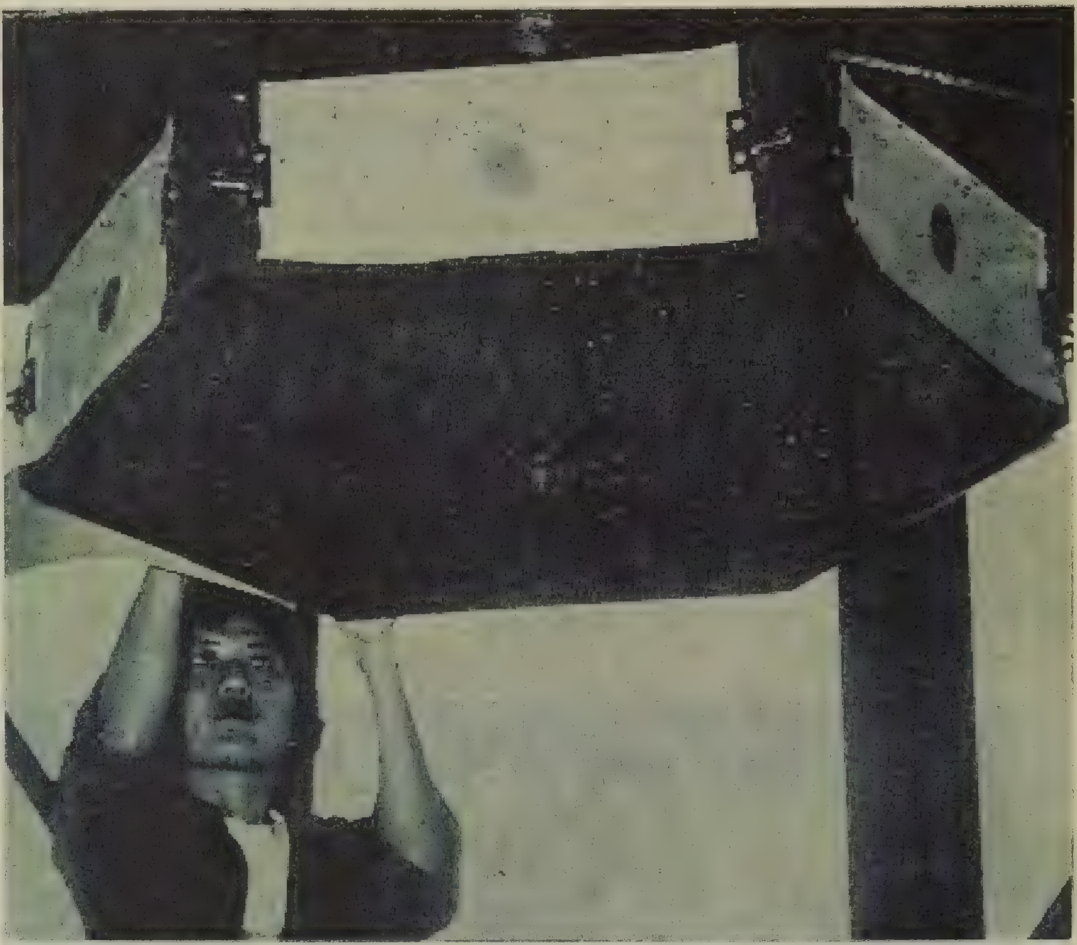


FIGURE 2.—Conducting wick tests in the olfactometer.

to determine whether a lure would be useful in dry traps, whether it would be persistent, and whether it could be used in combination with a toxicant.

In the supplemental tests the horizontally mounted wheel and traps of the olfactometer were replaced with a hexagonal prism 6 inches thick (fig. 2). Each of its six faces was covered with a piece of kraft paper, to the center of which was fastened a cotton wick 1½ inches long. This wick, treated with 0.5 ml. of the candidate lure, was attached with cellulose tape in such a way that the lure could not touch the paper. The lures were exposed for 15 minutes, and their efficiency in comparison with that of a standard lure was determined by estimating the number of flies that congregated on or near each wick. Any repellency from high concentrations of the lure could be observed. A lure having this characteristic would be relatively ineffective for field use. If the flies fed on the lure, an insecticide was added to see if they would ingest the poisoned lure. Duration of effectiveness of lures was estimated by holding the wicks under standardized conditions and periodically testing them in the olfactometer along with a standard lure until they were no longer attractive.

The supplemental tests gave, with a minimum of test material, the information needed to set up field tests efficiently.

4

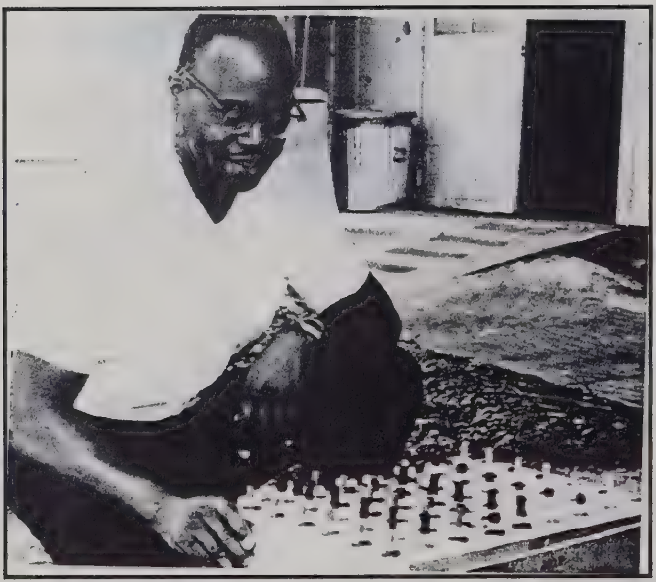
Dr. Beroza and another of his assistants, Benjamin Alexander, also invented cue-lure, which is, overall, the most effective and most commonly used melon fly attractant. They worked in conjunction with researchers at the ARS Hawaii Laboratory to test it. A brief account of cue-lure's invention and discovery goes as follows:

In 1960, Beroza, who got a lead from work going on in Australia, worked with Ben Alexander to synthesize cue-lure, a derivative of anisylacetone, which had been found to be an effective melon fly attractant by W. F. Barthel three years earlier, in 1957, but which lacked potency and would not attract immature melon flies.

Cue-Lure - $C_{12}H_{14}O_3$

But, Beroza would not know cue-lure's true effectiveness until scientists and technicians at the Hawaii Lab had tested it. Once again, Doris Miyashita is credited with the actual discovery of yet another attractant – cue-lure.

Doris Miyashita, a technician who worked at the Honolulu Lab for over forty years, is also credited with being the discoverer of cue-lure, the best male melon lure. ARS photo.



Dr. Ernie Harris headed the Hawaii Lab during the 1970s. Here he is studying the rate of volatilization of lures that are used to attract male fruit flies. ARS photo.

Two colleagues: Hawaii Laboratory Director Dr. Ernie Harris and Wallace C. Mitchell, Chairman of the University of Hawaii Entomology Department (picture circa early 1970s). ARS photo.

It's also interesting to note at this point a fascinating development in attractant research that occurred during Dr. Harris's tenure as the Hawaii Laboratory Director in the 1970s.

During that time, an English chemist named Mr. Hurt, who was employed by a British company named Food Industries Limited, had learned that a compound his company had been making for the food industry was very good at attracting melon flies.

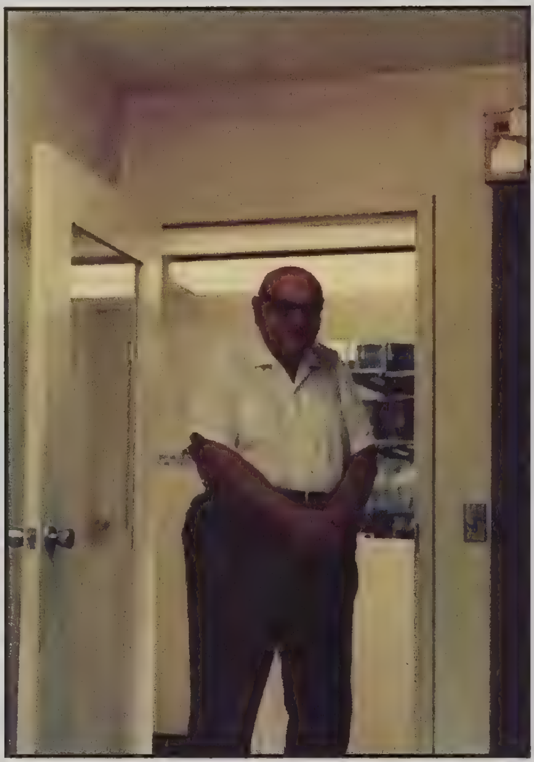
Hurt saw the potential value of this strange compound and sought to improve it. He then began looking worldwide, far beyond the realm of the food industry, for assistance in improving Food Industries' peculiar compound. In the course of his search, he became acquainted with the Hawaii Fruit Fly Laboratory and its attractant research.

Mr. Hurt contacted Ernie Harris, and Harris offered to see if his laboratory could improve Hurt's basic compound. Hurt then sent a sample to Harris who handed it off to entomologist-chemist Irving Keiser, then working with toxicants, attractants, chemosterilants, and hormones at the laboratory.

Circa 1970s, entomologist Irving Keiser of the Hawaii Laboratory (who had a genius IQ) showing a cage of experimental fruit flies to U. S. Navy officer pilots. Navy C-54 aircraft were being used for fruit fly experiments at that time. Keiser worked on developing a melon fly lure and other attractants, toxicants, chemosterilants, and hormones. ARS photo.

Keiser, while working to improve Hurt's sample, soon found that glycerin and other lard-like substances improved the persistence of Hurt's basic attractant.

While Hurt's compound, improved by Keiser, never matched cue-lure or raspberry ketone (another powerful male melon fly attractant) in effectiveness, this scientific sidebar does illustrate the Hawaii Lab's willingness to pursue scientific leads originating from unconventional sources – a good example of "thinking out of the box."



Dr. Irving Keiser at the Honolulu Lab near the end of his ARS career. J Armstrong photo.

Methyl eugenol, the most powerful of all fruit fly lures, was discovered, as ARS Hawaii Dr. Roy Cunningham once wrote, "through one of those serendipitous chances that delight us all," after entomologist F. M. Howlett learned, in 1912, that his neighbor in Pusa, India was pestered by flies after he'd sprinkled a few drops of citronella oil in his handkerchief for use as a mosquito repellent. Howlett's investigation of this phenomena revealed that all of the flies bothering his neighbor were males of the *Dacus zonatus* species, an important fruit fly pest.

Entomologist F. M. Howlett discovered methyl eugenol, the most powerful male oriental fruit fly lure, by chance in India in 1912. Although he documented his studies of this lure, it fell into obscurity until ARS Hawaii scientist Loren Steiner rediscovered it and put it to use as a weapon in the fight against the oriental fruit fly. CIA map.

Howlett later demonstrated in 1915 that methyl eugenol was the chemical component in the citronella oil causing attraction and concluded that what had occurred was an interesting example of an artificial means of sexual attraction; that is, the male fruit flies were sexually attracted to the methyl eugenol.

Methyl Eugenol - $C_{11}H_{14}O_2$

Prompted by this attraction, male oriental fruit flies would ravenously drink pure methyl eugenol offered to them until they filled their cups and died, yet strangely, methyl eugenol is not endogenously found in tephritid fruit flies themselves – no females of any fruit fly species carry the chemical in their bodies.

However, it is found in at least 25 plants, yet surprisingly, methyl eugenol is not found in the fruit flies' primary breeding host plants, one example being guava.

Despite the wondrous nature of Howlett's discovery, methyl eugenol was for all intents and purposes forgotten until 1946, when the oriental fruit fly was discovered in Hawaii and it became imperative to control this destructor of fruits and vegetables posthaste.

Dr. L. F. Steiner, then in charge of the Hawaii Lab, initiated a search for a lure to combat the oriental fruit fly and is credited (in 1952) with bringing methyl eugenol – the best of all male fruit fly lures – out of the darkness of the forgotten past in into the light of use in Hawaii and elsewhere as a powerful weapon in the war against the fruit fly.

Introduced into Hawaii in 1946, the oriental fruit fly quickly became a most destructive pest. Loren F. Steiner of the ARS Hawaii Lab rediscovered and introduced methyl eugenol into the battle against the oriental fruit fly. ARS photo.

Steiner's methyl eugenol, which was derived from a genus of tropical trees growing in India called Eugenia, attracted male oriental fruit flies at test sites on Oahu in such great numbers that 5-gallon buckets baited with methyl eugenol and an insecticide were over-filled with captured oriental fruit flies only a month after being set in the field.

Methyl Eugenol was brought out of obscurity by ARS Hawaii scientist Loren Steiner and introduced into Hawaii by him in 1952. One or five-gallon buckets baited with methyl eugenol and an insecticide would quickly fill with dead oriental fruit flies after being set in the field in Hawaii. E. Jang Photo.

Methyl eugenol soon became known as the "Miracle Attractant," and expectations ran high that methyl eugenol, combined with an insecticide, would eradicate oriental fruit flies in Hawaii. (Since its discovery, hundreds of natural and synthetic compounds have been comparison tested against methyl eugenol, but none have proved superior.)

However, the reservoir of flies was so great in Hawaii that researchers at the Hawaii Laboratory later concluded that male annihilation techniques alone could not control this pest.

Research to create an attractant called latilure for Malaysian fruit flies (*B. latifrons*), which was not identified in Hawaii until 1983 and is the least prevalent of the four fruit fly species in Hawaii, was begun in Hawaii, with early latifrons survey work being done by Dr. Roger Vargas, Dr. Ernie Harris, Dr. Nicanor Liquido of the Hawaii Lab, and Toshiyuki Nishida of the University of Hawaii on Kauai, Oahu, and Molokai. Vargas and Nishida were among the first scientists to document the life history and demographic parameters of the species.

Dr. Roy Cunningham played a leading role in field-testing, along with Hawaii-based biologist Grant McQuate, and entomologists Steven Peck, Ernie Harris, and Nicanor Liquido, as well as Dr Robert Flath ARS chemist (retired) of the Albany, CA lab.

In 2000, biologist Grant McQuate of ARS Hilo, here holding bio-lure trap, worked with other scientists to develop and test latilure, an effective Malaysian fruit fly attractant. Dr. McQuate continues to develop improved methods for detection/monitoring of tephritid fruit fly populations through efforts to improve upon attractants currently in use and through field-testing of alternative trapping systems. ARS photo.

Another powerful male medfly attractant, ceralure, was synthesized by Beltsville chemist Terrance P. McGovern and tested by Roy Cunningham in 1988. Ten year later an improved synthesis of the most active portion of ceralure was made by Beltsville chemist Andre S. Raw and tested in Hawaii by Eric Jang and colleagues. Raw's synthesis of ceralure B1 proved superior to McGovern's ceralure and trimedlure in most – but not all – tests conducted in Hawaii and at other locations, but it has not replaced trimedlure, due primarily to the increased cost of synthesis of the improved products.

Roy T. Cunningham of the ARS Hilo, Hawaii Lab invented ceralure with T. P. McGovern in 1988. ARS photo.

Other attractants research was carried out by Dr Nicanor Liquido, who evaluated analogs of methyl eugenol and cure-lure for improved attraction to melon fly and oriental fruit fly (chemicals closely structured to known attractants) respectively. Liquido's research, in cooperation of chemists Al Demilo and Ashot Khriman, from the same Beltsville lab as Dr. Beroza, looked at analogs to further improve on the male lure success. Liquido, along with technicians Grant McQuate (now research scientist) and Charmaine Sylva tested these analogs in the field and found several that showed some promise.

Search for a female lure for the Mediterranean fruit fly started in the 1960's under research chemist Kiichi Ohinata, who with Beltsville chemist Martin Jacobsen first tested a pheromone-like attractant. (Pheromone: A chemical substance that is produced by an

animal and serves esp. as a stimulus to other individuals of the same species for one or more behavioral responses.)

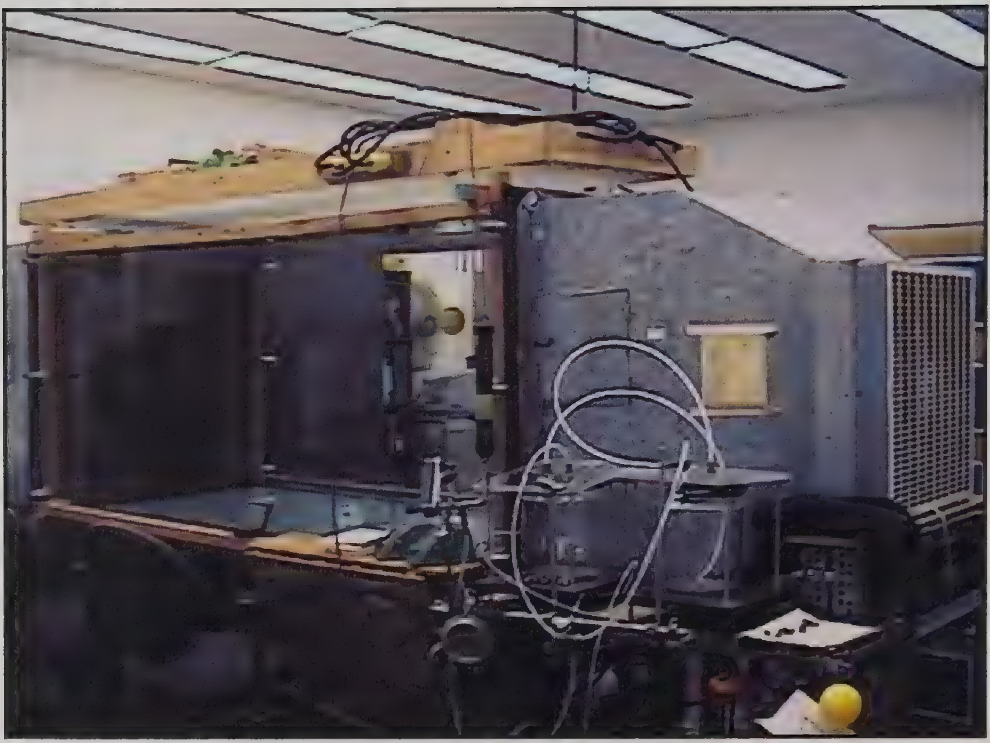
Chemist Kiichi Ohinata is credited as being the first scientist to search for a female medfly lure. He tested a pheromone-like attractant for medfly. Early 1970s ARS photo.

Although they never commercialized a product, the idea of a pheromone-based attractant for medfly was revisited 20 years later by Eric Jang and his staff, who initiated a new program on fruit fly sensory physiology and behavior. Dr. Jang took an approach that did not rely on the "needle in a haystack" approach of screening of thousands of chemicals, but rather started looking at the fly as an indicator of putative or supposed chemicals that might be attractive.

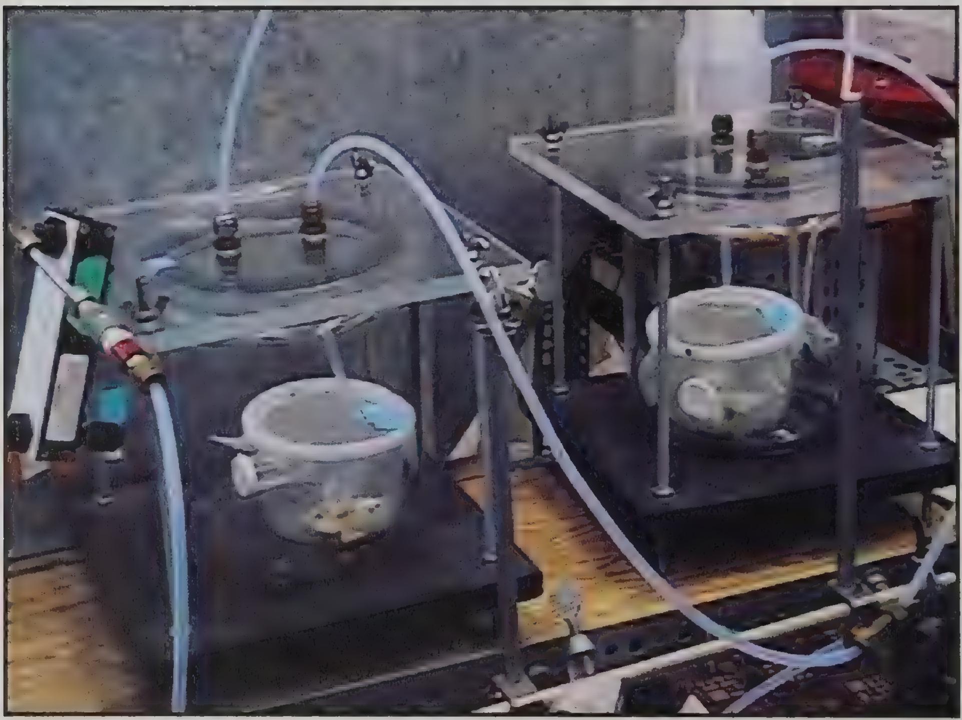
Along with colleague Dr. Douglas Light from the ARS laboratory in Albany, CA, Dr. Jang also set up the first sensory physiology lab employing sensitive electrophysiological technique call the “electroantennogram”. This method measured the electrical response from the fly’s antenna in response to chemical odors. Drs. Jang and Light along with technicians Esther Schneider, Janice Nagata and Lori Carvalho evaluated many chemicals that were identified from various fruits and vegetables as well as the sex pheromones with the help of ARS chemists Robert Flath, and chemists of the Albany lab and of the Beltsville lab.

Dr. Doug Light. Eric Jang photo.

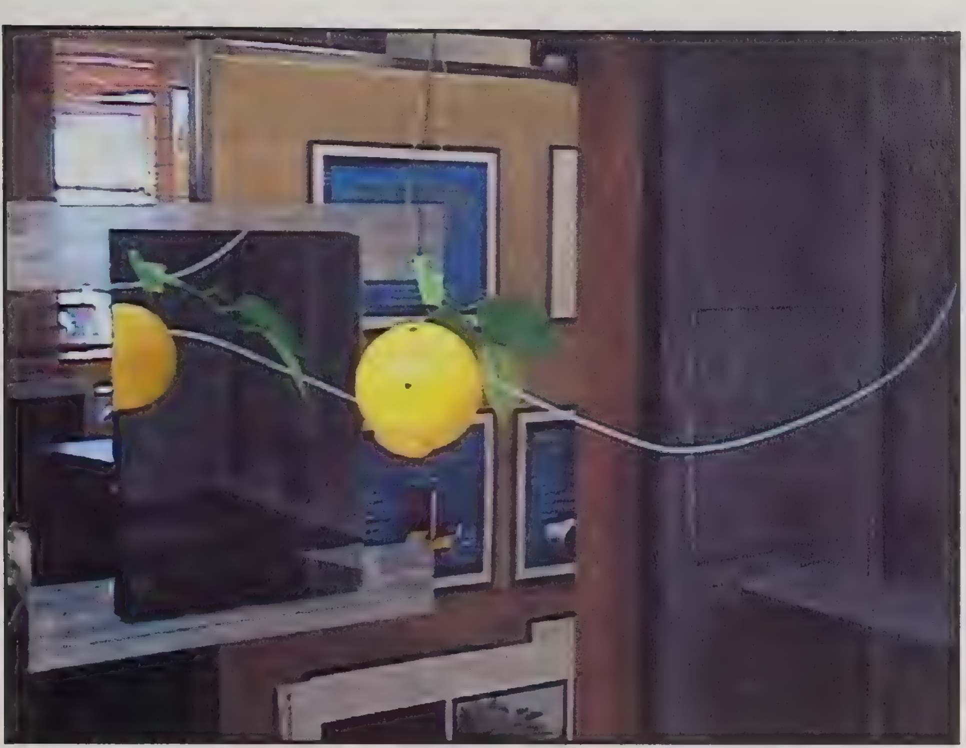
The team further expanded the scope of their research to look at specific behavior of flies to various chemicals with the help of insect behavioral areas or flight tunnels in which the flies directed behavior to chemicals could be observed and documented. These new approaches provided the basis further basic knowledge on the basis for behavior and the influence of various chemical classes of compounds to fly attraction.



This is the laboratory flight tunnel in Dr. Jang's Hilo Lab. It is a laminar airflow wind tunnel used to study the response of insects to olfactory stimuli. It measures 0.9m x 0.9m x 2.8m. Technician Lori Carvalho photo.



Here is the glass chamber outside of the flight tunnel, which contain the odor sources being tested. Compressed air is pumped into the glass jars and the volatiles from each jar are pumped into the flight tunnel through Teflon tubing. Lori Carvalho photo.



This picture shows a yellow sphere used as a fruit model. The odors from the outside chambers get pumped into the fruit model. The insects are released on a platform 2.0 m downwind of the fruit models. Insects are allowed to fly upwind to observe flight behavior to the different odors. Landings, arrestment time and oviposition are measured to each sphere emitting the odor being tested. Lori Carvalho photo.

At present, Research Leader Dr. Eric Jang continues ARS's fruit fly semio-chemical attractant work on the Big Island, Oahu, and Kauai. ARS photo.

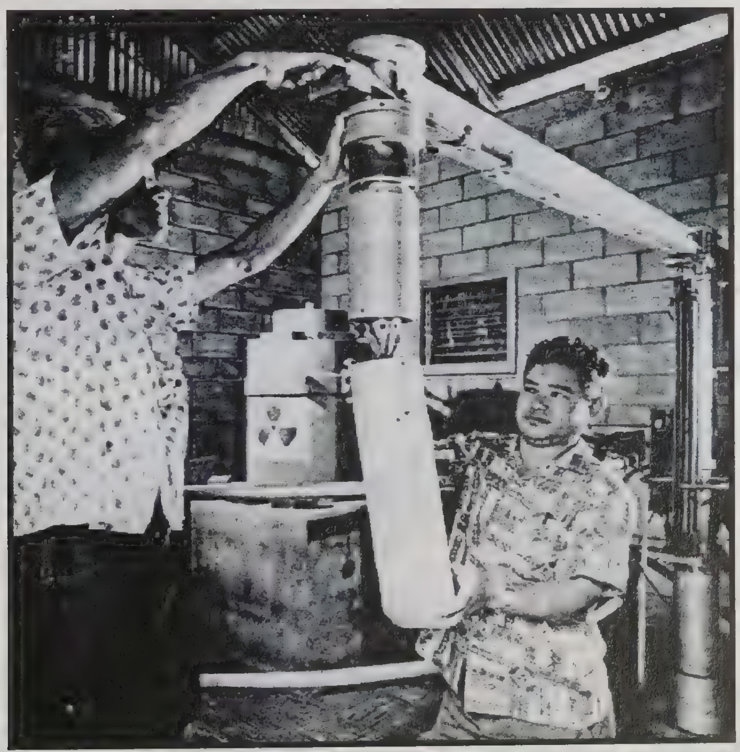
Dr. Jang's goal is to develop improved attractants for tephritid fruit flies for use in detection, monitoring, and suppression of tephritid fruit fly populations. Laboratory and field experiments are currently being conducted on the Big Island and Kauai to improve fruit fly attractants either by preparing analogs of established male lures or by preparing fractions of known or unknown chemically complex compounds known to be either directly attractive or known to synergize the attractiveness of established tephritid fruit fly attractants, with analogs and/or extracts sent to the lab at Hilo for standardized bioassay tests.

Chapter Five

The Great Bonin and Marianas Island Eradication Programs of the Early 1960s

In the 1950s, scientists at the ARS Hawaii Laboratory began to use radiation to sexually sterilize male fruit flies.

And, in the early 1960s, the Hawaii Laboratory put these sterilized male flies to the test by conducting large scale eradication programs, first in the Bonin Islands and later on islands in the Marianas, which involved the release of vast numbers of laboratory-reared male fruit flies sterilized by irradiation.



Isao Tomikawa (left) and entomologist Hitoshi Kamasaki sterilizing fruit flies at the Manoa Lab by irradiating them in the pupal stage of their development, early 1970s. ARS photo.

In this photo taken in 2004, thirty or so years later, lead technician Rich Kurashima at the Manoa Lab is preparing to irradiate pupae in the lab's newest irradiator in much the same manner as it had been done in Tomikawa's and Kamasaki's time. ARS photo.

Theoretically, it was thought that if sterilized male fruit flies could be released into an area in numbers many times larger than the population of wild fruit flies and then mate with wild females, egg hatching would be prevented. And by continuing to release massive numbers of sterile male fruit flies through several generations, the wild fruit fly population would decrease and eventually be eradicated.

The concept for this sterile insect technique (SIT) was originated by world-renowned entomologist and long-time director of the Agricultural Research Service and ARS Hall of Fame member Dr. E. F. Knipling, and was proven successful in eradicating the screw-worm fly, the scourge of the cattle industry, from the United States by 1966.

ARS Hall of Famer Dr. E. F. Knipling pioneered the sterile insect technique (SIT). ARS photo.

In this picture Martin Fujimoto left, and entomologist Hitoshi Kamasaki of the Hawaii Lab are packing sterilized pupae for air shipment to Guam in the Marianas. ARS photo, circa early 1960s.

Another powerful area-wide control and eradication technique developed, tested, and put into practice by the Hawaii Laboratory during the 1960s in the Bonin and Marianas Islands was male annihilation technique (MAT).

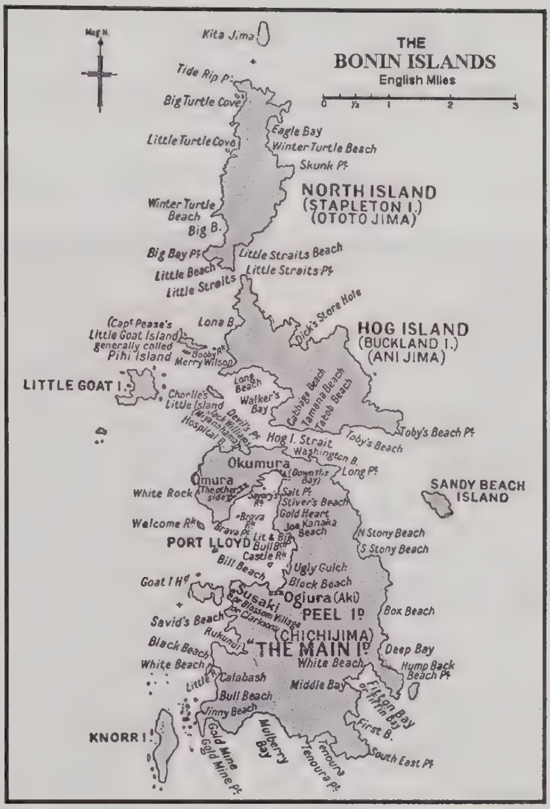
This technique combines an attractant, such as methyl eugenol or cue-lure, and an insecticide, which in combination will attract and then kill male fruit flies.

Basically, male annihilation in the Bonins and Marianas worked as follows: Cardboard wafers saturated with an attractant and an insecticide were released from aircraft over Chichijima Island in the Bonins, and later over Rota, Saipan, and Tinian in the Marianas. Once on the ground, the attractant lured large numbers of male flies that were killed by the insecticide. Without male fruit flies present, the females could not mate and oviposited infertile eggs only, which did not hatch.

Aircraft such as the one seen in this picture were used to transport sterilized flies from Hawaii to Guam for later release in the Bonin and Marianas Islands. ARS photo.

The Bonin Islands Eradication Program

In 1960, the Honolulu Laboratory began work on eradicating the oriental fruit fly in the Bonin Islands using both the sterilized male and male annihilation techniques.



The Bonin Islands south of Japan were the site of an ARS Hawaii program to eliminate the oriental fruit fly in 1960. From *The History of the Bonin Islands*, Cholmondeley, 1915

During the course of the Bonin program, oriental fruit fly pupae sterilized in Honolulu were flown to the laboratory's Guam facility about every two weeks aboard Pan American Airline's aircraft. On Guam, the pupae were received and repackaged into drop boxes.


Pupae were sent to Guam from Hawaii for repackaging into boxes for release by airplane. ARS photo.

These boxes were then loaded aboard Navy Grumman flying boats that Navy pilots, accompanied by Hawaii laboratory personnel, flew from Guam to the Bonins, where the freshly emerged sterile flies were released above Chichijima Island.

Here, Martin Fujimoto is dropping boxes of sterile flies from an airplane. Note map showing flight drop lines the aircraft will follow for dispensing flies and the safety belt around Martin's waist. E Harris photo.

Dr. Roy Cunningham drawing flight drop lines on a map at his desk in Guam, early 1960s. E Harris photo.

Navy pilots also flew male fruit fly annihilation (MAT) runs to the Bonins from Guam with cargoes of cardboard wafers containing methyl eugenol and an insecticide

that Hawaii-based scientists and technicians (among them Martin Fujimoto and Wallace Mitchell of the University of Hawaii, serving three to four month tours of overseas duty) would release from the air.

Due to the long combined distances between Hawaii and Guam in the Marianas Islands, and between Guam and the Bonin Islands, the Bonin program proved awfully difficult to support logistically. Consequently, the Bonin Islands eradication program was discontinued in favor of a program in the Marianas Islands that the Guam facility could better support.

Eradication Program in the Marianas Islands

Because of demanding logistical problems inherent in the Bonin Islands eradication program, the Bonin program was discontinued in favor of a new program in the Marianas Islands in the early 1960s. CIA maps: Northern Marianas left, & Guam right, which is located to the south of the Northern Marianas.

During the 1930s and 1940s, the melon fly and the oriental fruit fly were introduced into the Marianas Islands, where melons were and still are particularly popular and where several melon crops can be grown prior to the onset of the typhoon season in June.

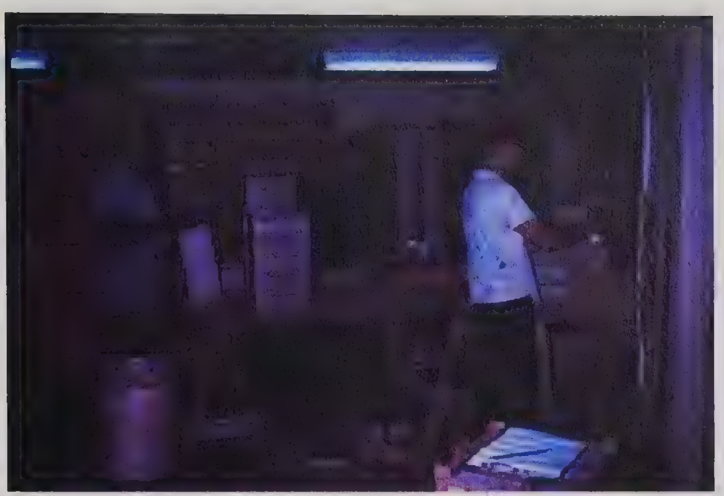
To combat these pests, the Hawaii Laboratory joined forces in the early 1960s with the

U. S. Navy and the Trust Territory of the Pacific in a cooperative effort to eradicate the melon and oriental fruit flies from the Marianas by using a combination of male annihilation (MAT) and sterile insect techniques (SIT), along with spot protein bait treatments.

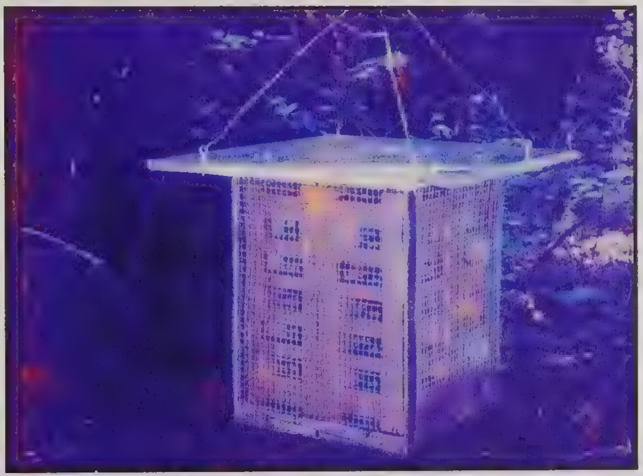
The sterile male fruit fly technique proved to be extraordinarily successful in the Marianas, where the release over a billion sterile melon flies that had been irradiated as pupae in a Cobalt-60 irradiator in Hawaii resulted in the eradication of the melon fly from Rota, a 33-square-mile island in the Marianas, during 1962 and 1963.

Concurrent with the melon fly eradication program on Rota, was the application of the male annihilation technique, which resulted in the eradication of the oriental fruit fly on Rota in 1965, also. Thus, by 1965, both the melon fly and the oriental fly had been eradicated on Rota.

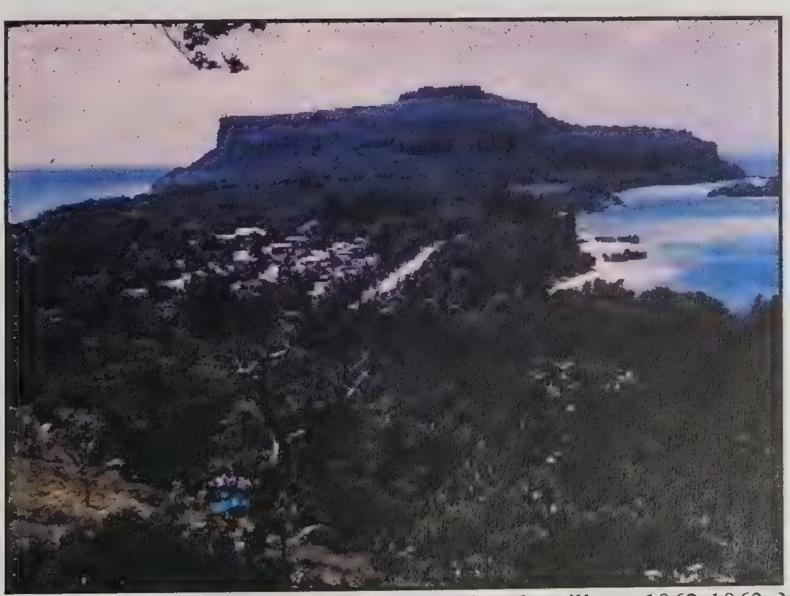
Here, Dr. Ernie Harris and Joe Quan, his Guamanian assistant, are treating wafers with methyl eugenol and Dibrom toxicant before climbing aboard a Navy airplane and dropping them on Rota to eradicate the oriental fruit fly. Harris and Quan did over 95% of the dropping of sterile melon flies and methyl eugenol applications on Rota that resulted in the eradication of both the melon fly and oriental fruit fly from Rota. Others, among them, Loren Steiner, Kiichi Ohinata, and Irving Keiser worked in the Marianas, also. E Harris photo.



Dr. Ernie Harris, Joe Quan, and Martin Fujimoto at work preparing drop boxes prior to the boxes being released over Rota from a U. S. Navy airplane. 1962-1963. E Harris photo.



Ground release cage for releasing melon fly into inaccessible areas not covered adequately by aerial release. E Harris photo.



Song Song Village on Rota as seen from the hill overlooking the village, 1962-1963. Note two sunken ships on right in the harbor. E Harris photo.

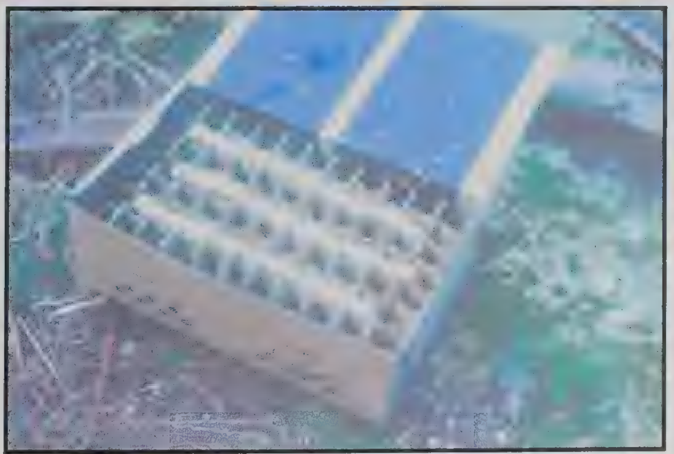

Friendly residents of the island of Rota in the Marianas, circa 1962-1963. E Harris photo.


Fruit holding boxes containing fruits and vegetable collected on Rota. E Harris photo.


Plateau on Rota with mango and breadfruit trees in the background. E Harris photo.

Cucumber plantings on Rota. E Harris photo.

Ben Masa, a Rota native, was hired to count fruit fly trap catches and perform other duties as assigned. E Harris photo.



A drop box with sterile melon flies along with 3 wicks saturated with honey to provide food for the flies. The flies were put in the boxes as pupae and when they emerged they could eat some honey before being dropped on Rota where they needed to find food in the field. E Harris photo.

Dr. Harris loading wicks with honey into drop boxes to feed melon flies before they are released over Rota, 1962-1963. E Harris photo.

Dr. Ernie Harris back home in Hawaii and at his desk at the old University of Hawaii Laboratory location after a demanding tour of duty in the Marianas, early 1960s. E Harris photo.

Hurricane Karen ripped through Guam while the Marianas fruit fly eradication program was underway. Here is some of the terrific damage done to the town of Pati, Guam. E Harris photo.

Dr. Roy Cunningham looking directly at airplane, Guam. Early 1960s. E Harris photo.

The cooperative eradication effort in the Marianas achieved a third smashing success later, between 1962 and 1965, when the oriental fruit fly was eradicated on Guam, a 210-

square-mile island, and Saipan, Tinian, and Aguiguan as well, by using the male annihilation technique.

With this accomplished, the oriental fruit fly was eradicated from the Marianas Islands, the very place from whence it was believed to have come to Hawaii in 1946, and it has not been detected there since. This was the first successful demonstration of male annihilation of the oriental fruit fly. Also during 1962 and 1965, the melon fly was eradicated from Saipan, Tinian, and Aguiguan, but not from Guam, with SIT.

Another attempt to eradicate melon flies on Guam with SIT was made in 1969 without success.

A Grumman Albatross flying boat. Aircraft similar to this one were flown by U.S. Navy pilots and used by the Hawaii Laboratory to drop sterile male fruit flies and cardboard wafers containing an attractant and an insecticide over the Bonins and the Marianas in the early 1960s. Grumman Albatross Website photo.

Chapter Six

Mass Rearing of Fruit Flies and their Parasites

Presently, ARS Hawaii's Manoa Laboratory houses fruit fly and parasitoid rearing facilities, which supply millions of eggs, larvae, pupae, and adults of the Mediterranean, oriental, melon fly, and several species of parasitoids to various research and cooperative agencies in Hawaii, the U. S. mainland, and foreign countries.

ARS Rearing, Genetics, and Radiation Facility in Manoa Valley, Oahu. ARS photo.

Yet, the mass-rearing techniques used today at Manoa that are needed in order to wage war against fruit flies were unknown prior to 1949, when mass-rearing research first began in Hawaii.

Before 1946 and the introduction of the oriental fruit fly into Hawaii, melon flies and Mediterranean fruit flies had been captured in the field and bred at the ARS's Hawaii Lab to produce small numbers of progeny for use in scientific experiments, but there had been no pressing need to rear them in great numbers.

However, an urgent requirement for mass rearing arose with the appearance of the oriental fruit fly. Fruits, vegetables, nuts, and flowers that had been grown commercially in Hawaii before the advent of the oriental fruit fly met with disaster in the late 1940s, since the range of plants, particularly citrus, that the oriental fruit fly affected was much greater than the that of the melon and Mediterranean fruit flies. For the first time, the fruit fly became a truly great problem in Hawaii. Simple techniques like bagging fruit to protect them against fruit fly stings that had kept melon and Mediterranean fruit fly damage under control proved entirely impractical against the oriental fruit fly.

In order to expand research, large numbers of uniform, adult oriental fruit flies were needed immediately for experiments.

The oriental fruit fly, shown above with technician and fruit fly bucket trap, was introduced into Hawaii in 1946. Mass rearing of fruit flies began in Hawaii in order to produce large numbers of experimental oriental flies urgently required by researchers. Hawaii Area-Wide IPM photo.

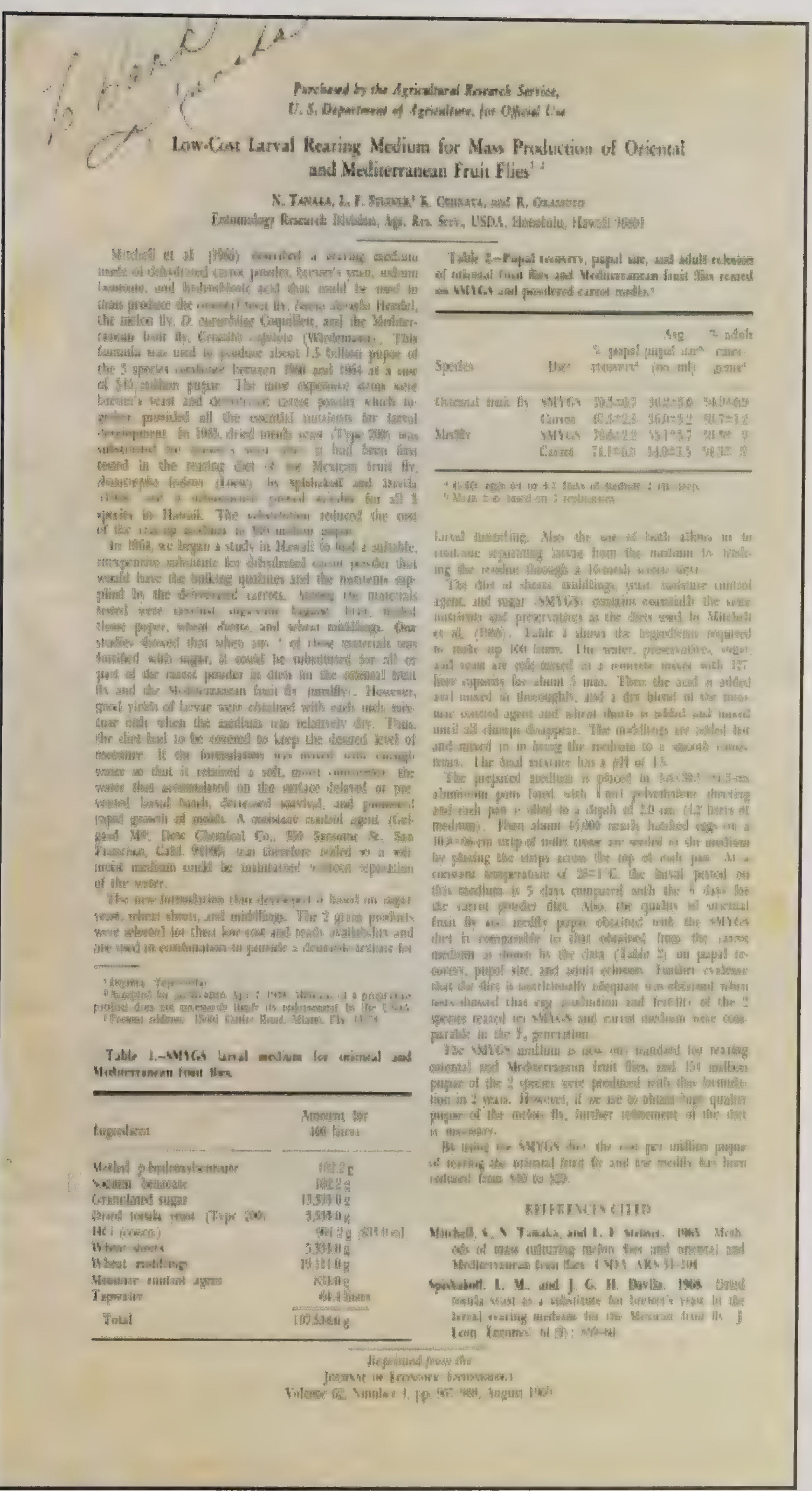
The University of California took the lead by pioneering rearing research at its Hawaii Laboratory with scientists Ken. S. Hagan, G. L. Finney, and Shizuko "Sue" Mitchell (who later worked for ARS).

They were the first people to rear the oriental fruit fly, the first to rear fruit flies under aseptic conditions, and the first to attempt the mass rearing of fruit flies of any species.

In this photo taken in 2003 at the Manoa Lab, Sue Mitchell is seat on the left. She was a pioneer in the field of mass rearing of fruit flies while working with the University of California in Hawaii, 1949-1951. She later worked for the ARS in Hawaii. To her left are former ARS Hawaii employees Doris Miyashita (the discoverer of trimedlure and cue-lure), entomologist Richard Kobayashi, and former technician Martin Fujimoto, who worked in the Bonins and the Marianas during the 1960s. Unidentified man far right. E Jang photo.

Entomologist Norimitsu "Nori" Tanaka, who candidly remarked in a 2003 interview that he only "went to school to eat lunch" as a kid growing up in Honolulu, joined the Hawaii Lab in 1953 as an assistant and went on to discover, invent, and develop techniques that are still used to this day throughout the world in the field of rearing fruit flies. Because of his pioneering efforts and exceptional expertise in this area, he is known today as the "Father of Rearing".

Building on the foundation of Hagan, Finney, and Mitchell's work in the early 1950s, Norimitsu Tanaka, an innovative, hard-working entomologist shown here at work in the Manoa Lab during the early 1970s, went on to become "The Father of Rearing". Much of what is known today about rearing fruit flies has come from Nori's work. ARS photo.



Purchased by the Agricultural Research Service,
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Low-Cost Larval Rearing Medium for Mass Production of Oriental and Mediterranean Fruit Flies

N. Tanaka, L. F. Steiner, K. Ohinata, and R. Okamoto

Autographed copy of *Low-Cost Larval Rearing for Mass Production of Oriental and Mediterranean Fruit Flies*, 1969, by N. Tanaka, L. F. Steiner, K. Ohinata, and R. Okamoto is still the standard publication for rearing of fruit flies.

Richard Okamoto, circa 1970s, preparing larval medium for mass rearing of fruit flies. ARS photo.

In the 1980s-1990s, young Dr. Roger Vargas headed the rearing unit (and the radiation and genetics units) in Honolulu that developed rearing methods for the Malaysian fruit fly. J Armstrong Photo.

Dr. Roger Vargas and Shizuko "Sue" Mitchell teamed up to invent an artificial carrot and wheat diet to replace the expensive fresh pepper diet used to rear Malaysian fruit flies during 1983 through 1984. For the first time, the Malaysian fruit fly was successfully reared on an artificial diet, and further research by Vargas, Mitchell, and others resulted

in improvements. Dr. Vargas also spearheaded research to develop simple, low cost techniques and equipment for large-scale production of *D. latifrons* – another first.

Dr. Stella Chang of the Manoa Lab works on developing better diets for rearing fruit flies. A greater understanding of nutritional requirements of tephritids could mean not only cheaper production costs, especially with mass rearing, but also possibly more rational and efficient pest management. ARS photo.

Dr. Chiou Ling Chang has developed a chemically based meridic diet (*Ceratitis capitata* #1) for the Mediterranean fruit fly larvae. The meridic diet was also used as a base diet by Dr. Chang to pioneer the development of a complete chemically defined adult Mediterranean fruit fly diet (*C. capitata* #2 diet).

This work demonstrated for the first time that both adults and larvae of C. capitata require similar nutrients for survival, and also proved that defined diet-fed adults produce significantly more eggs than those fed a protein hydrolysate/sugar diet. For the first time

scientists were able to use this type of diet to conduct adult dietary deletion studies to test chemical interactions, which affect adult longevity and their reproductive performance.

Dr. Chang has also been the pioneer in developing a novel liquid larval diet for melon fruit fly. This research demonstrated for the first time that larvae of Bactrocera cucurbitae could survive in a liquid diet.

Photo of medly larvae in Dr. Chang's liquid diet. C. L. Chang photo.

Used solid diet materials had been disposed of at cost for many years prior to Dr. Jang's research into finding ways of recycling these materials. These diets, although contaminated with dead fruit flies, were nutritious, and Jang's work led to their being used as forage and feed for animals, like pigs, which is now saving the Oahu APHIS facility $30,000 to $100,000 per year in disposal costs.

Geneticist Dr. Don McInnis of the Manoa Laboratory works to improve the quality of mass-reared sterile insects, especially of medflies, employing the sterile insect release method (SIRM). He is currently using several different approaches: development of more efficient genetic sexing (males-only) strains, development of improved adult and larval

diets for mass-rearing, genetic selection for improved behavioral or morphological traits in lab-produced flies, and development of field-based quality control methodology to monitor strain fitness in the field.

Gregor Mendel (1822-1884). Mendel's work became the foundation of modern genetics.

Dr. McInnis's work, and the work of all modern geneticists (those scientists engaged in that branch of biology which deals with heredity and variations of organisms), has its origins in the findings of Gregor Mendel, for it was Mendel who first derived the basic laws of heredity. After many years of thorough and meticulous study, Mendel learned that hereditary factors do not combine, but are passed intact; and that each member of the parental generation transmits only half of its hereditary factors to each offspring (with certain factors "dominant" over others); and different offspring of the same parents receive different sets of hereditary factors.

In this photo, we see geneticist Dr. Don McInnis of the Manoa Lab examining the T-1 strain of melon fly he invented. Male pupae of this strain are brown and female pupae are white, making it easy to eliminate females with a photoelectric sorter. ARS photo.

In referring to Mendel and his own work in the genetics of fruit flies, Dr. McInnis recently said, "As for Mendel, yes, he discovered the particular nature of genes, that they had caused traits like color, and pupal color in my case, with the flies. Like some of his traits, some are dominant and some recessive, like the white pupal color. Once we found the mutation, we characterized it; then we went further in creating a chromosome alteration to link the normal trait for pupal color (brown) to the male sex, while females stay white."

Geneticist Dr. Don McInnis working in field cage at Honolulu Lab. E Jang photo.

The Hawaii Laboratory's research also led the way in the mass-rearing of fruit fly parasitoids for release in nature to augment natural parasitoid populations and thereby enhance the parasitoids capability to suppress fruit fly populations. Knipling's book *Principles of Insect Parasitism Analyzed From New Perspectives*, 1992, showed that the suppression of fruit fly populations by augmentative releases of parasitoids is theoretically possible.

Yet, nearly a decade earlier, Dr. Ernie Harris did pioneering work in the rearing of fruit fly parasitoids in the laboratory, which would later serve as the basis for implementing parasitoid release programs. He was the first to begin rearing parasitoids in the Honolulu laboratory. In 1983, Dr. Harris demonstrated that *Fopious arisanus*, Hawaii's most numerous and effective fruit fly parasitoid, could be reared successfully, and was the first to develop a laboratory strain of *F. arisanus*. The thriving colony of *F. arisanus* he created was named the "Harris Strain."

An *F. arisanus* colony was first successfully reared in 1983 by Dr. Ernie Harris of the Hawaii Laboratory and was named the "Harris Strain." ARS photo.

Dr. Ernie Harris on left and former ARS Hawaii entomologist Dr. Renato Bautista (now with the State of Hawaii) in a papaya orchard. Harris's innovative techniques produced the first laboratory reared *F. arisanus* fruit fly parasitoids. ARS photo.

Recently, Dr. Ernie Harris commented upon the concept of augmentative biological control versus classical biological control: "When natural enemies are released in the environment (a vegetable crop) to suppress a pest insect population, this is application of augmentative biological control. The natural enemies could originate from a laboratory colony or could be collected from a population in the field. It is possible that

augmentative biological control could be applied one or more times during the year. The concept of classical biological control is applied when a pest insect becomes established in a new area where its natural enemies are absent. In this case the pest insect could multiply and form large damaging populations causing a lot of destructions without control by natural enemies. In this situation a logical approach is to visit the place of origin of the insect pest and collect natural enemies and take them to the location (new home) where the new outbreak has occurred and release them to reduce unimpeded multiplication of the pest insect in the new environment. Before the natural enemies are released they are held in quarantine and checked for hyper parasites. Precautions are taken to ensure that the imported parasites are not a problem themselves."

Entomologist Tim Wong of the Honolulu Laboratory then took Harris's pioneering work a step further by developing the mass-rearing techniques for parasitoids necessary for augmentative release.

Dr. Harris provided this information on Tim Wong's work: "Tim Wong conducted ecological studies on oriental fruit fly, melon fly and medfly on the island of Kauai and at Kula, Maui. The work he did on Maui had the greatest scientific impact, particularly his wok on medfly ecology in Kula. Tim also initiated mass rearing of *D. longicaudata* and *D. tryoni* fruit fly parasitoids. He was the first to demonstrate successful control of medfly with SIT and *D. tryoni* parasitoid releases in combination. Tim was the first to demonstrate mass rearing of the larval parasitoids when he was awarded funds at the behest of Dr. Ed Knipling for parasitoid release work on Kauai."

And, research geneticist Dr. Don McInnis had this to say about his colleague Tim Wong's work with fruit fly parasites: "As for Tim's contributions to rearing, he was instrumental in getting very difficult parasitoid rearing to be possible, even if expensive. And Mo (technician Noboru Mochizuki) was his main man as far as carrying out Tim's ideas. Mo also had many ideas of his own to try out to improve the rearing of parasitoids. Tim also developed ways to bring wild flies into culture and conducted mating tests using wild flies from natural hosts. He had to develop ways to handle adults carefully, determine the proper age to conduct the tests, when the flies were all sexually mature, and he also developed standardized methods of running mating tests in field cages.

"Tim's main effort was to develop the rearing methods for several species of tephritid parasitoids, including the proper conditions to promote mating of the parasitoids (not a simple matter), the timing of when to expose the females to the fruit fly host (egg or larva), and the exposure time, another critical period. From the successful larval rearing, Tim was then able to work out the best ways to handle the adults in cubical cages and standardize a proven method to expose the host to the parasitoids for progeny production. All of these methods were published in peer-reviewed journals and Tim was recognized as a true leader in his field. One of his best accomplishments, and maybe the best in my mind, was the demonstration that the combination of SIT and parasitoid releases was a potent control method, and indeed the two could even act synergistically."

Dr. Ernie Harris recently commented further on what Dr. McInnis mentioned on the subject of the combination of SIT and parasite releases (BC or biological control) to control fruit flies: "The application of BC and SIT requires a precise knowledge of the ecology of the pest species you want to apply these technologies to suppress. The best environment for application of SIT often is not the best environment for BC. In sensitive areas, study of the environment often shows that one or two domesticated or wild host fruit plants may support the explosion of a fruit fly population that would not occur if fruit fly production from these plants were suppressed. This is the kind of situation where parasitoid augmentation is most effective. The AW-IPM is the arena in which these technologies can be demonstrated and in which they can sustain each other. We are the unit that should show the way on how to combine and effectively use these technologies."

And here, Dr. Harris gives us insight into mass rearing of parasites for augmentative release: "Mass rearing of parasites for augmentative release involves mass production of parasites specifically to release them in large numbers for control of pest insect species by overwhelming them with natural enemies so that the numbers of pest insects are reduced by killing of the pest species by parasite inundation. Under normal conditions, there is a balance between the pest population and the parasite. When the pest population increases a month or so later the parasite population increases and the pest population goes down. This up and down shift in the pest insect population and the parasite is the normal pattern. When the pest population is subject to inundative augmentative release the pest population can be driven down to a lower level than is possible with natural control in the general environment."

Based on Harris's and Wong's work, the laboratory was able to perform many parasite releases on Maui. Then in the late 1990s, augmentative releases of *F. arisanus* were first practiced on Kauai.

For the Kauai releases, parasitized pupae reared in Honolulu were shipped by air to the Kauai station, where they were further reared to the sexually mature adult stage in cages, transported by truck to coffee and guava test fields, and released.

Drs. Roger Vargas, Ernie Harris, and Renato Bautista were most instrumental in the success of the Kauai releases, and the large-scale parasite rearing and release methods first put into practice and developed during the Kauai augmentative releases have since been transferred to Mexico, Guatemala, and French Polynesia by Dr. Vargas and have also been integrated into the ongoing Hawaii Area-Wide IPM program first set up and

coordinated by Research leader Jang and more recently by Vargas on the Big Island, Maui, and Oahu.

Dr. Roger Vargas on right, with Pacific Basin Agricultural Research Center Director Dennis Gonsalves, examines fruit fly-infested guavas exposed to *F. arisanus*, as part of the biological component of the on-going and highly successful Hawaii Area-Wide pest management program that Dr. Vargas coordinates. ARS photo.

Dr. Vargas is in the process of transferring integrated pest management techniques, including augmentative releases of fruit fly parasites - a technology originated and developed by the ARS Hawaii Lab - to French Polynesia, where fruit flies are a major pest. Here are a few of his French Polynesian assistants on a remote island south of Tahiti. R Vargas photo.

Spanish-speaking entomologist Dr. John Spencer headed the Honolulu rearing, genetics, and radiation unit at Manoa in the mid to late 1990s before signing on with the Animal & Plant Health Inspection Service in Guatemala. At last report he was serving at another APHIS facility in Mexico. ARS photo.

Chapter Seven

Toxicants and Bait Sprays

Over the years, the Hawaii Laboratory has also carried on evaluations of insecticides in both laboratory and fields tests. The laboratory's goal is, and has been, to discover new insecticides with "promise" – insecticides that possess high toxicity toward fruit flies and low mammalian toxicity, without being a threat to the natural environment.

Early research on toxicants used for fruit fly control was headed up by Mr. Irving Keiser who evaluated hundreds of toxicants in the lab with the help of technician Esther Schneider and others. Keiser not only studied the effectiveness of toxicants, he also dabbled into other areas of fruit fly physiology studying attractants, chemosterilants and repellents in his lab in Manoa. After Keiser's retirement much of the toxicant research was led by Dr Roy Cunningham who spearheaded efforts to refine the male annihilation technique (MAT) where a male specific lure was combined with toxicant. Cunningham developed several methyl eugenol (oriental fruit fly) and cue lure (melon fly) baits that could be applied aerially. His research resulted in one of the first demonstrations of area-wide melon fly control using cue lure applied aerially on the island of Rota where melon fly was reduced over 95% using MAT alone. Cunningham then teamed up with entomologist Nicanor Liquido to evaluate the use of photoactive dyes as potential replacements for malathion in fruit fly control. Their research and resulting demonstration resulted in their receiving numerous national awards for environmentally compatible methods for fruit fly control. Unfortunately the use of photoactive dyes have not had widespread application in the U. S. to date.

Another insecticide that was refined developed and tested by ARS Hawaii in the 1990s was Suredye, which is composed of fruit fly bait made up of a precise combination of sugars, proteins, and other ingredients that attract fruit flies and stimulate them to feed, and phloxine B, also known as FDA-approved red dye #28. The bait tricks fruit flies into consuming the dye that quickly kills them once they are exposed to light.

In this picture are former ARS Hawaii entomologist Nicanor Liquido and Hilo technician John Ross applying combinations of red dye and bait mixtures to cotton wicks for testing to determine which mixture med flies prefer. ARS photo.

Former ARS entomologist Dr. Nicanor Liquido and retired entomologist Roy Cunningham ran tests of Suredye in coffee fields on Kauai in the mid-1990s. Both scientists received commendations for their work. ARS photo.

Medfly feeding on Suredye soaked into a cotton wick. ARS photo.

Work on toxicants continues today, with Dr. Roger Vargas leading the way.

Dr. Roger Vargas with former ARS Hawaii technician Bob Gibbons (now at Beltsville, Maryland), 2000. Roger is applying bait droplets to coffee leaves at Hilo, Hawaii. ARS photo.

ARS Hawaii entomologists Roger Vargas and Jack Armstrong, ARS Hawaii biologist Grant McQuate, and former ARS Hawaii entomologist Steve Peck (now at Brigham Young University in Utah), and others, went on to test and develop spinosad, an "environmentally friendly," non-organophosphate insecticide against fruit flies during the late 1990s.

Derived from a naturally occurring soil dwelling bacterium called *Saccharopolyspora spinosa,* a rare actinomycete that was discovered by chance and first collected from soil in an abandoned rum distillery in the Caribbean in 1982 by a vacationing scientist, it was later formulated into insecticides that attack a fruit fly's nervous system after being ingested. It kills the insect within one to two days.

Spinosad is a principal ingredient of GF-120 Fruit Fly Bait developed as a joint project between ARS scientists in Weslaco Texas and Dow Agro-Sciences (Indianapolis, IN) and sprayed on the borders of fruit and vegetable gardens, provides an environmentally

satisfactory (compared to malathion, for example) fruit fly toxicant-protein bait combination.

Biologist Dr. Grant McQuate applying the highly effective GF-120 fruit fly bait mixed with spinosad insecticide on a crop border. Dr. McQuate works on developing improved methods of suppression of tephritid fruit fly populations by conducting laboratory toxicology tests and field suppression trials with potential environmentally friendly toxicants. ARS photo.

The first Area-Wide demonstration of spinosad bait spray was done on Kauai in the late 1990s by ARS Hawaii scientists and technicians. Stanford University map.

Still another insecticide, one that is undergoing field-testing by Dr. Roger Vargas and is a promising replacement for malathion, is fipronil, a highly active, broad-spectrum insecticide from the phenyl pyrazole family. This insecticide disrupts a fruit fly's central nervous system by blocking the passage of chloride ions through the GABA receptor, an inhibitor of the central nervous system, which causes hyperexcitation of insects' nerves and muscles. It is dispensed in small cardboard wafers ("widgets") in combination with an attractant such as methyl eugenol or cue-lure.

At a secluded Polihale, Kauai test site, 2 bucket traps, each containing 1 fipronil+cue-lure wafer, are set next to bitter melon, a host plant of the melon fly. R Vargas photo.

Dr. Eric Jang is now (2005) testing a novel method of killing oriental fruit flies attracted to methyl eugenol. Based on the seminal research of Dr Keng Hong Tan, retired professor of entomology at the University of Science Malaysia in Penang, Jang and Tan are testing chemicals that interfere with the oriental fruit fly's ability to metabolize methyl eugenol to pheromone components. Blocking the pathway that leads to normal metabolism of methyl eugenol results in eventual death of the insects.

Chapter Eight

The Hawaii Area-Wide Integrated Pest Management Program Launched in 1999

In 1999, the Agricultural Research Service financed an Area-Wide, fruit fly integrated pest management (IPM) program for Hawaii, with the objective of implementing primarily ARS-developed technologies to help Hawaii's farmers control the four species of fruit flies causing economic damage in the State of Hawaii.

Essential to the success and sustainability of this program was cooperation among the ARS, the University of Hawaii, the Hawaii State Department of Agriculture, the USDA-APHIS (Animal & Plant Health Inspection Service), local farmers, and the general public. For the first time in Hawaii, these agencies and the public joined together to cooperate as a team in implementing a successful Area-Wide Integrated Pest Management program.

Hawaii Area-Wide IPM Program leaders observing a bait-sprayed crop border on a farm in central Oahu are left to right: Dr. Roger Vargas of ARS Hawaii, Research Leader Dr. Eric Jang of ARS Hawaii, Dr. Lyle Wong of the Hawaii State Department of Agriculture, and Dr. Ronald Mau of the University of Hawaii at Manoa. Hawaii Area-Wide Pest Management IPM photo.

Stuart Stein left, director of the APHIS Hawaii Fruit Fly Rearing Facility at Waimanalo, Oahu, and Dr. Eric Jang examine larval diet. ARS photo.

Community Education

Educating Backyard Gardeners & Communities

Dr. Roger Vargas points out differences between melon flies and medflies to member s of the community. Hawaii Area-Wide Pest Management IPM photo.

Grower Education

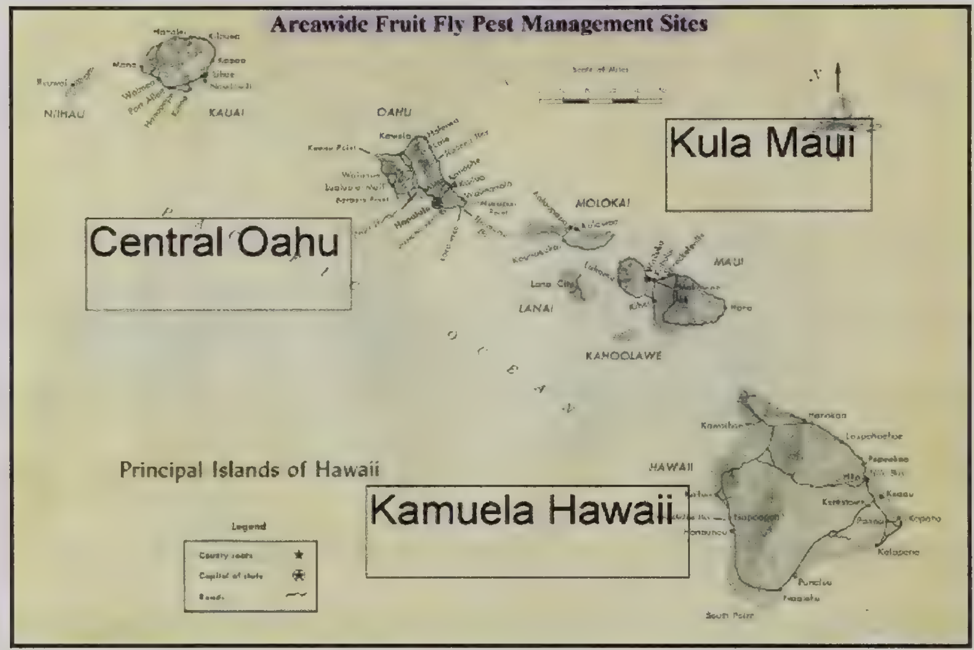
Educating Hawaii's Growers

Technician Mike Klungness working with a farmer to implement ARS-IPM technology. AW- IPM photo.

Hawaii Area-Wide IPM coordinator Dr. Roger Vargas inspecting bananas with farmers on Oahu. Hawaii Area-Wide IPM photo.

The program, which began in 1999 under the leadership and direction of Eric Jang, had been funded for up to five years and has been highly successful. Dr Jang led the initial evaluations of potential demonstration sites, gathered the critically important support and collaboration of researcher Dr Ron Mau from the University of Hawaii, Cooperative Extension Service, Dr Lyle Wong from the Hawaii Dept. of Agriculture, Mr. Stuart Stein of USDA APHIS, and growers and private business to initiate the Area-Wide program. The program coordination was then transferred to Dr Vargas who continued the collaboration, expanded the initial sites and increased the funding of the program to its current level. Drs. Mau, Wong, Vargas, Jang, Mr. Stein, and members of the advisory committee continue to provide leadership to this award-winning program. Growers in Kamuela, Hawaii; Kula, Maui; and Central Oahu (the Area-Wide IPM sites) have seen their yields increase, and the use of organophosphate insecticides has been reduced.

With the Hawaii Area-Wide IPM program, farmer's yields have increased and use of organophosphate fertilizers has decreased to produce a bounty of healthy fruits and vegetables such as those shown in this ARS photo.



Three sites were selected to implement the Area-Wide IPM program in Hawaii: Kamuela on the Big Island, Kula, Maui, and Central Oahu. Raymond E. Lanterman-H Soboleski map.

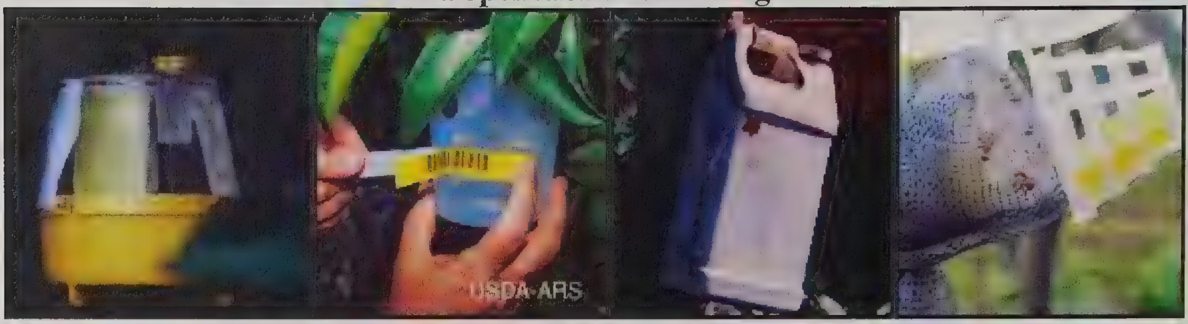
Furthermore, environmentally acceptable technologies are now legally available in Hawaii for the first time to control fruit flies thanks to the Area-Wide IPM program – the use of GF-120 bait sprays being one technology already transferred to farmers and smaller growers for their benefit. Additionally, for the first time in Hawaii, methyl

eugenol was available to farmers and growers, by means of a special needs permit, for control of oriental fruit flies.

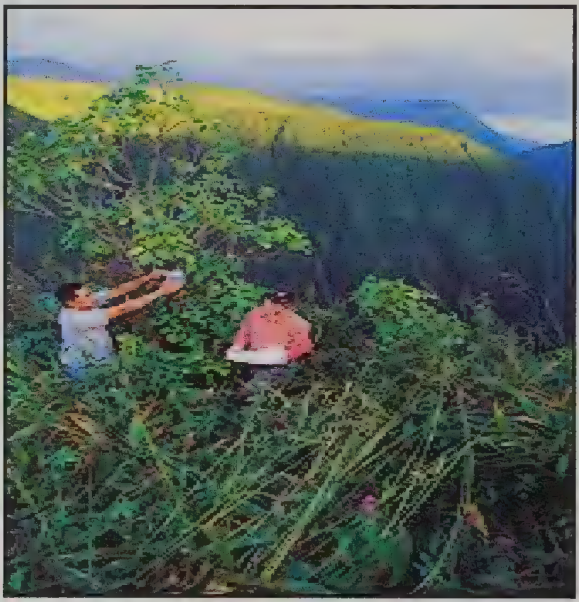
Technician Gregory Boyer spraying GF-120 bait spray at Kamuela, Hawaii. This technology is now available through the Area-Wide IPM program to farmers and growers to suppress fruit fly populations and reduce crop damage. Hawaii Area-Wide IPM photo.

This chart shows the six components of the Area-Wide IPM Program. Hawaii Area-Wide IPM chart.

Population Monitoring



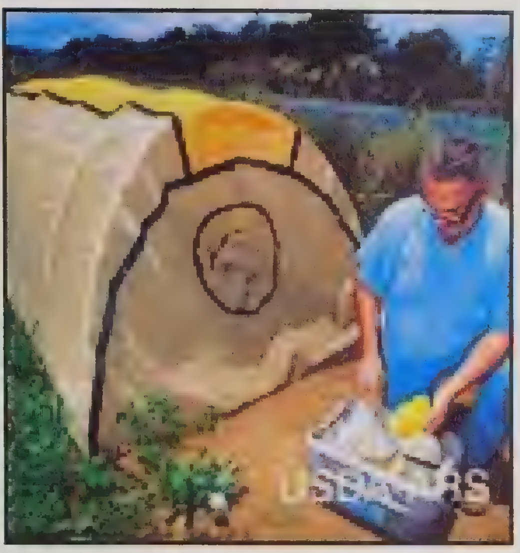
Male lures and food-based attractants are used to monitor fluctuations in fruit fly populations. Flies are lured into traps for collection and are then counted to estimate fruit fly population. From left: Biolure trap, bucket trap, grower trap, and a male fruit fly lure. ARS and Hawaii Area-Wide IPM photos.



Technician Charlie Lee and ecologist Hannah Revis at a beautiful population-monitoring trap site on Big Island.

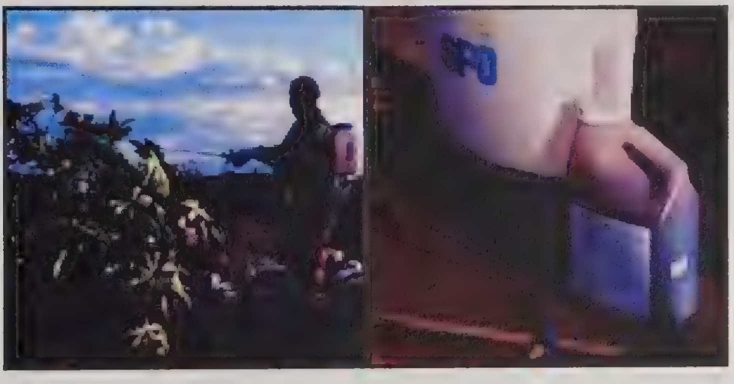
Field Sanitation

Practicing good field sanitation will reduce fruit fly populations. It consists simply of removing infested fruit from the field. Damaged or rotten fruit can be buried or bagged for disposal. Hawaii Area-Wide IPM photos.



Technician Mike Klungness with an augmentorium. Infested fruit are kept inside this cleverly made, tent-like structure, where larvae can then be confined to prevent their escaping. Yet, fruit fly parasitoids that may develop from the fruit are small enough to escape through a specially designed mesh at the top. Hawaii Area-Wide IPM photo.

Protein Bait

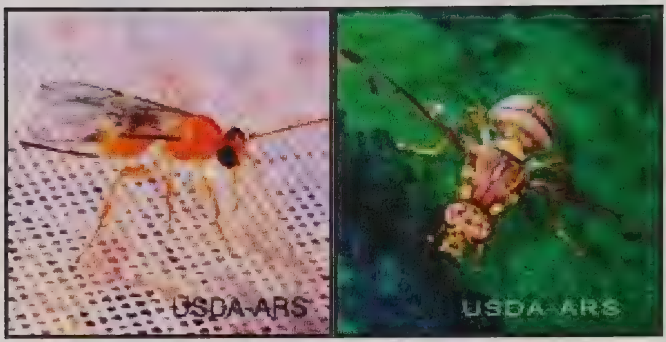


Protein baits sprays used at low volumes on borders and in growing areas reduces fruit fly populations. GF-120 combines protein bait with spinosad, an environmentally safe toxicant. Hawaii Area-Wide IPM photos.

Male Annihilation

Male annihilation bucket trap on left will contain an attractant and a toxicant. Large numbers of these types of traps are set over a wide area ("area wide"). The lure attracts male fruit flies that are then killed by the toxicant. On right, male lure in plastic cage. Hawaii Area-Wide IPM photos.

Sterile Insects and Parasitoid Insects



Fruit fly parasite left, and melon fly right. Releases of sufficient numbers of parasites and sterile male fruit flies are another component of the Area-Wide IPM Program. With these releases, fruit fly populations can be maintained at or below economically acceptable levels. ARS photos.

The cooperation of local farmers and growers was essential to the success of the area-wide pest management program:

In summary, Program Coordinator Dr. Roger Vargas has written: "…the Hawaii Fruit Fly Area-Wide Pest Management team has developed the first successful area-wide control program for four exotic fruit fly species in Hawaii. Future plans for the program include establishing new demonstration sites, suppression of new species, releases of sterile flies by air, and, most importantly, expansion into other agricultural and suburban areas beyond the demonstration sites. Interest is keen among farmers and homeowners, as news of the program's success has spread. The environmentally friendly technologies and practices resulting from this program will help protect American agriculture from the impact of devastating fruit fly invasions, and alleviate the dependency on conventional pesticide use. This very successful program is enhancing the diversification of agriculture for Hawaii, improving the economic base of rural areas and small farmers, and providing a much-needed supply of fresh fruits and vegetables fundamental to nutrition and health. Consistent with the United State's role as an international leader in agriculture, this program is being pursued as a model for fruit fly suppression in areas of the world where adequate nutrition is lacking."

Chapter Nine

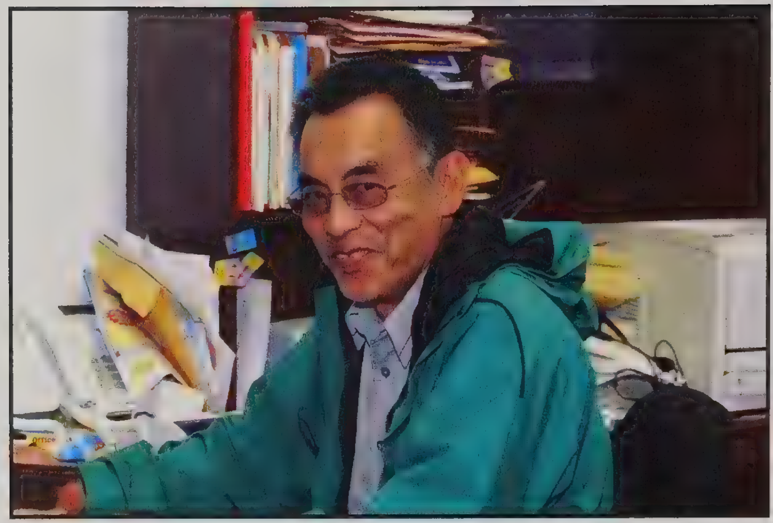
Administration

Administration provides essential support fruit fly research. Payroll, purchasing, travel, and personnel-processing are several of the functions of this unit.

The following photos of present-day administrative personnel were taken by Hilo technician and expert photographer Les Oride in March of 2005:

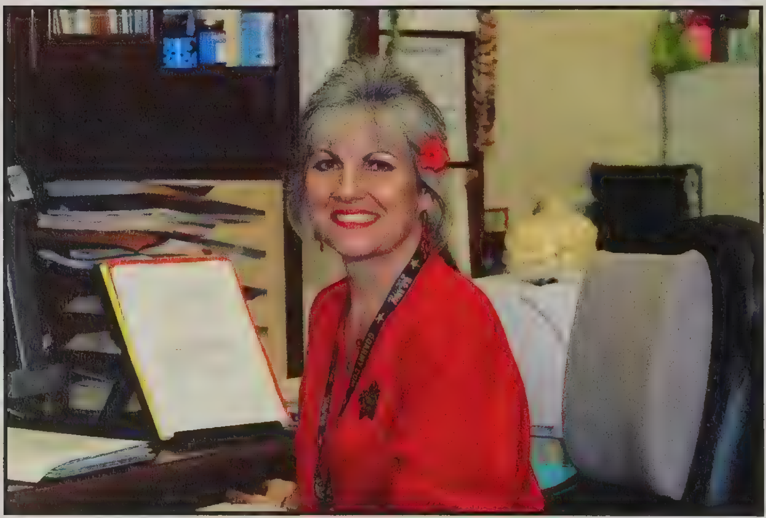
Personable and professional - timekeeper and secretary, Loretta Okamoto. Les Oride photo.

Norma Ross is Center Director Dennis Gonsalves' Secretary and chief of staff. Les Oride photo.



Myles Taniguchi is PBARC's Administrative Officer. Les Oride photo.

Accountant Judi Nakamoto. Les Oride photo.



Travel specialist Marilyn F. Tagalicod. Les Oride photo.


The administrative staff of PBARC: Marilyn Tagalicod, Carolyn Unser, Purchasing Agent Barbara Ueda, Judi Nakamoto, Donya Bolos, Myles Taniguchi, Norma Ross, and Albert Lee of facilities maintenance. Les Oride photo.

Chapter Ten

The Continued Growth and the Merging of the ARS Hawaii Fruit Fly Laboratory into PBARC

With the introduction of the oriental fruit fly into Hawaii in the mid-1940s, the fruit fly research program in Hawaii was enlarged once again. The Hawaii Laboratory also joined with several agencies, within and without Hawaii, to work cooperatively to battle this latest destructive pest.

From 1949 though 1951, the Hawaii Laboratory teamed up with the Hawaii Sugar Planters Association (HSPA) Experiment Station, the Pineapple Research Institute, the University of California, the Hawaii Territorial Department of Agriculture, and the University of Hawaii in a cooperative effort to develop new methods of control, which included the collection and introduction of additional parasitoids from Asia and Africa into Hawaii.

Even further expansion of the program occurred when a laboratory was established in 1949 on the island of Hawaii, and with its access to large test plots provided by private and state cooperators, it has been in operation continuously to this day.

Heading the Bureau's fruit fly program in Hawaii at that time was Director Dr. Walter Carter. "Sir Walter" also led the Pineapple Research Institute, as well as the aforesaid cooperative research effort. Walter Carter's Personnel Chart of September 1949 listed a Honolulu Headquarters and five Project Groups: Chemical Control, Commodity

Treatments, Area Control, Ecology-Biology, and Biological Control, with a total staff of 42 scientists, technicians, and clerical staff located in Honolulu, Hilo, Maui (a temporary substation), and Lanai (another temporary substation).

Project Leaders in 1949 were: Commodity Treatments, J. W. Blalock; Area Control Project Honolulu, C. F. Henderson; Area Control Project Lanai, I. Keiser; Biological Control Project Honolulu, D. W. Clancy; Chemical Control Project Honolulu, L. F. Steiner; Ecology-Biology Project Maui, K. L. Maehler; Ecology-Biology Project Hilo, C. J. Davis, and Ecology-Biology Project Honolulu, N. E. Flitters.

An ARS fruit fly laboratory was first established on the Big Island in 1949 at the intersection of Lanikaula and Kilauea Streets in Hilo. Map by Map Quest.

In 1959, ten years after the Big Island Lab was established, three people were employed at the Lab's downtown Hilo laboratory: Technicians Gilbert Farias, Tadao Urago, and entomologist Susumu Nakagawa. ARS photo.

In 1965, new facilities were built on the Big Island at the University of Hawaii farm near Hilo, which are now called the PBARC Laboratory.

The Big Island Fruit Fly Lab moved to its present, now PBARC, location in 1965. PBARC map.

And on Oahu in 1973, the Hawaii Laboratory moved from its University of Hawaii campus building – a place it had occupied for 42 years – to a facility it erected in space provided by the university at 2727 Woodlawn Drive.

Dr. Darrell Chambers, left, was Honolulu Lab Director during the late 1960s and early 1970s. Dr. Eric Jang is seated at right. E Jang photo.

Following Dr. Chambers as head of the Hawaiian Fruit Fly Laboratory was Research Leader entomologist Ernest J. "Ernie" Harris, whose tenure ran from 1972 until 1979.

Dr. Ernie Harris. Another achievement that the Hawaii fruit fly lab accomplished under Harris's leadership (1972-1979) was the successful eradication of the first med fly outbreak in California during 1975-1976 by applying the sterile insect technique. Others involved were: Ohinata, Seo, Keiser, Wong, Cunningham, Tanaka, Komura, Fujimoto, Higa, and Higgins. E Harris photo.

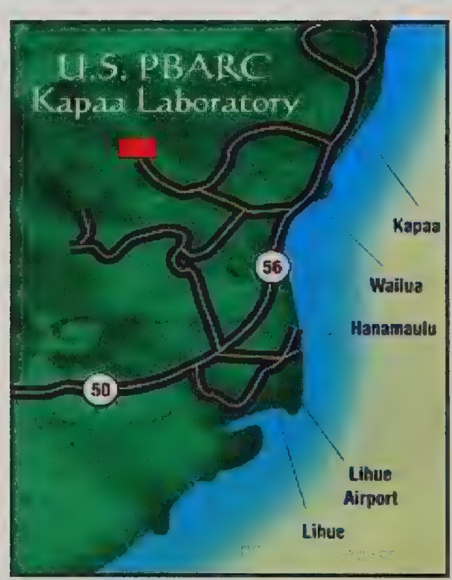
During Dr. Harris's tenure as Research Leader, Kenneth Y. Yamaguchi served as Harris's Administrative Officer, and scientists serving in Harris's Methods Development

for Detection, Control, and Eradication of Fruit Flies unit at Honolulu included: entomologists Irving Keiser, Richard M. Kobayashi, William J. Schroeder, and Norimitsu Tanaka. Chemist Kiichi Ohinata was also present.

Also located in Honolulu was the Methods Development for Treating Infested Products unit led by chemist Stanley T. Seo.

Two scientists worked in the Field Studies for Detection, Control, and Eradication of Fruit Flies unit in Hilo: entomologists Roy Cunningham and Susumu "Sus" Nakagawa.

A Kauai station was established in 1985, with two laboratories being built, one at Barking Sands and the other in Wailua.



The Kauai Station was established in 1985. PBARC map.

In the mid-1990s, staffing was reduced on Kauai and the Barking Sands location was closed, so that only a staff of five technicians now remain at Wailua to provide technical assistance to scientists located in Honolulu, on the Big Island, and elsewhere.

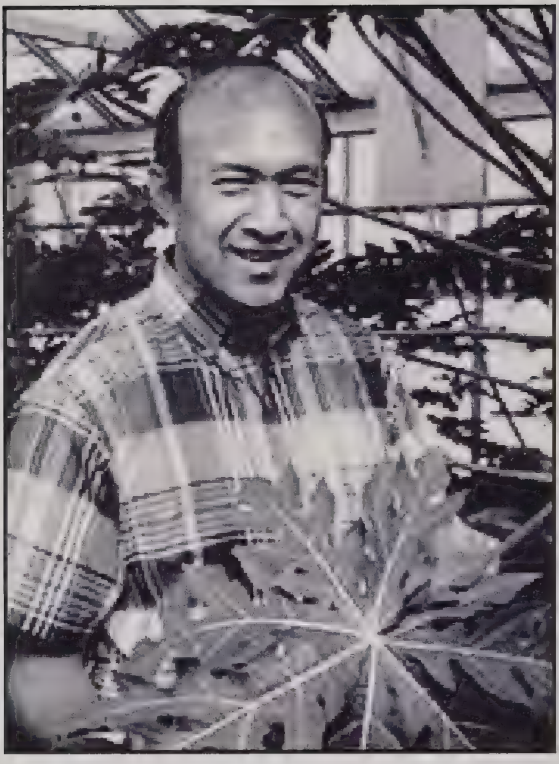
In 1999, the Pacific Basin Agricultural Research Center was established with the following mission:

"The mission of the U.S. Pacific Basin Agricultural Research Center is to develop basic and applied information to strengthen agriculture in Hawaii and the Pacific Basin in an environmentally acceptable and sustainable manner by managing and developing tropical plant genetic resources, developing new technologies and germplasm for improving crop productivity by reducing physiological and disease constraints, developing and demonstrating appropriate strategies for managing crop pests, providing economically viable technologies for controlling quarantine pests, ensuring product quality and safety, and increasing economic returns."

And, in the same year and at the same time that PBARC was founded, the Hawaii Fruit Fly Laboratory, first established in Hawaii in 1912, merged with other units to form PBARC.

Currently, PBARC's Administrative offices and the Center Director's Office are located on Aupuni Street in downtown Hilo.

Administrative and Center Director's office are currently located in downtown Hilo. PBARC map.



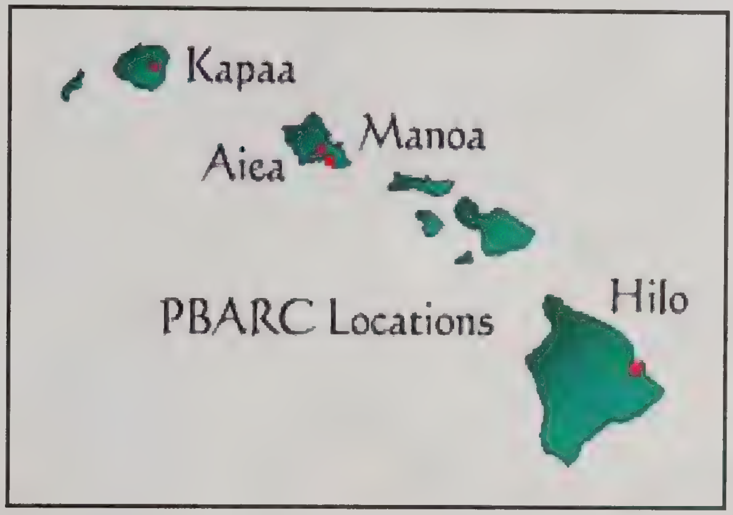
Center Director Dr. Dennis Gonsalves was born and raised at Kohala on the Big Island and was a distinguished plant geneticist at Cornell University for many years prior to taking over as the head of PBARC in 2001. ARS photo.

The Postharvest Tropical Commodities Research Unit headed by Dr. Jack Armstrong, and the Tropical Plant Pests Research Unit led by Dr. Eric Jang are located at the PBARC research facility on Stainback Highway in Hilo. In the past, these units did fruit fly research only. Now, Armstrong's unit has already expanded beyond fruit fly research only, by doing research on other insect pests.

Also located at the Stainback Highway research facility is the Pacific Basin Tropical Plant Genetic Resources Management Unit, managed by Dr. Frances Zee. Since being founded in 1986, this unit's mission is to collect, identify, evaluate, maintain, utilize, preserve, and distribute important clonal germplasm for designated tropical fruit, nut, beverage, and ornamental crops.

The Tropical Plant Physiology, Disease, and Production Unit is located at Aiea, Oahu and is under the direction of Dr. Paul Moore.

Plans are also now underway for a brand-new PBARC facility to be constructed in Hilo that will centralize ARS's scientists and technical staff in Hawaii by 2008, and will be committed to a variety of agricultural research in cooperation with researchers on state, national, and international levels.



PBARC location map, 2005.

In March 2005, the following personnel were engaged primarily in fruit fly research or in support of or administration and management of fruit fly research:

CENTER DIRECTOR'S OFFICE

BOLOS, DONYA T.; GONSALVES, DENNIS; NAKAMOTO, JUDITH (JUDI) R.; ROSS, NORMA N.W.; TAGALICOD, MARILYN F.; TANIGUCHI, MYLES H.; UEDA, BARBARA J.; UNSER, CAROLYN H.

HILO

ARMSTRONG, JOHN (JACK) W.; BARR, PAUL G.; BROWN, STEVE A.; CARVALHO, LORI A.F.N.; CALVERT, FRANCES; CHAN, CHERYL M.Y.N.; CHANEY, NANCY; DORAN, KRISTI; FOLLETT, PETER A.; HIRAMOTO, MATTHEW; JANG, ERIC B.; KETTER, HEIDE M.; KLUNGNESS, LESTER (MIKE) M.; LEE, ALBERT T.; LEY, JILL; LOWER, ROBERT (BOB) A.; MCQUATE, GRANT T.; MILLER, NEIL W.; NAGATA, JANICE T.; NISHIJIMA, KATE A.; OKAMOTO, LORETTA L.; ORIDE, LESLIE (LES) K.;OTA, DONNA T.; ROBARDS, ELIZABETH (BETH); SANXTER, SUZANNE (SUZY) S.; SCHNEIDER, ESTHER L.; SHISHIDO, VINNIE M.; SIDERHURST, MATTHEW; SILVA, SANDRA T.; SYLVA, CHARMAINE D.; URAGO, TADAO (NMI); VARGAS, ROGER I.; WALL, MARISA M.; WHITE, FEROL

HONOLULU

ALBRECHT, CHRISTOPHER P.; BROWN, CHARLES R.; CHANG, CHIOU LING (STELLA); HARRIS, ERNEST (ERNIE) J.; HEINIG, REBECCA; HOWLEY, THERESA; ICHIMURA, DWAYNE M.; KAWAMOTO, DANIEL S.; KOMATSU, JASON S.; KURASHIMA, RICK S.; LIM, RON R.; MANGINE, THOMAS E.; MCINNIS, DONALD (DON) O.; MURASAKI, NOAL; MUROMOTO, DARIN; SEO, DANNY M.; SHIGETANI, KEITH K.; SHINGAKI, KENT T.; SILVA, JOHN; TAKANO, JEFFREY I.; TAM, STEVEN Y.; UCHIDA, GRANT K.; VALDEZ, ROMEO

KAPAA

BRINKMAN, CHARLES (CHUCK) M.; IJIMA, RUSSELL T.; RODD, CHARLES (CHARLIE) E.; SOBOLESKI, HENRY (HANK) S.

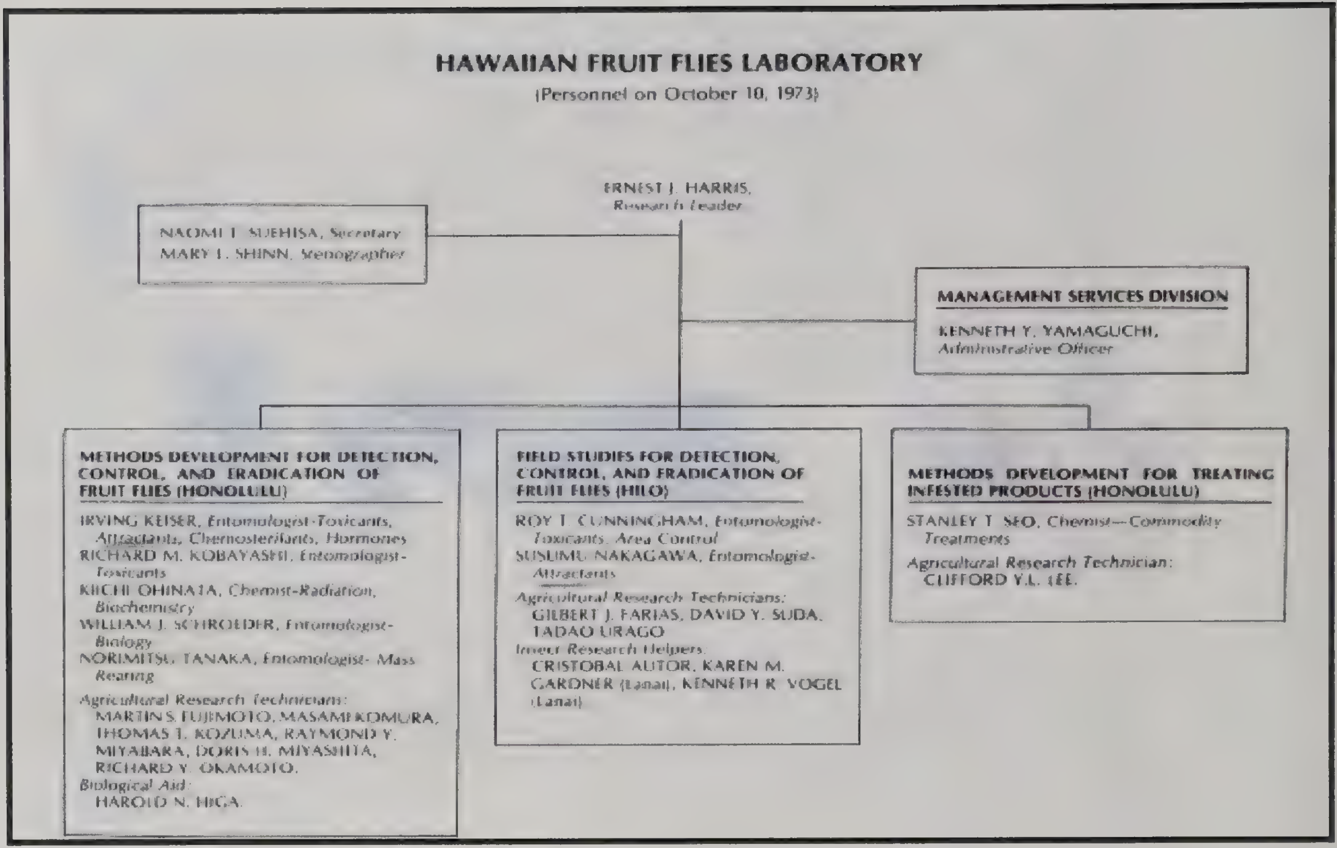
KAMUELA

BOYER, GREGORY J.; KAWABATA, ALBERT H.; LEE, CHARLES C.; OKAMURA, WAYNE

Present Pacific Basin Agricultural Research Center scientists engaged in fruit fly research:
From top left: Dr. Ernie Harris, Dr. Jack Armstrong, and Dr. Eric Jang.
Middle left to right: Dr. Roger Vargas, and Dr. Don McInnis.
Bottom: Dr. Chiou Ling "Stella" Chang, Dr. Grant McQuate, and Dr. Peter Follett.
ARS photos.

ARS Honolulu Laboratory personnel, 1973: Seated Left to right: William Schroeder, Norimitsu Tanaka, Ernest Harris, Naomi Suehisa, Kiichi Ohinata, and Martin Fujimoto. Standing Left to right: Clifford Lee, Stanley Seo, Richard Okamoto, Harold Higa, Mary Shinn, Irving Keiser, Thomas Kozuma, Doris Miyashita, Raymond Miyabara, Masami Komura, and Richard Kobayashi. ARS photo.

ARS Hilo personnel, 1973, Left to right: Gilbert Farias, Tadao Urago, Roy Cunningham, Cristobal Autor, David Suda, and Susumu Nakagawa. ARS photo.



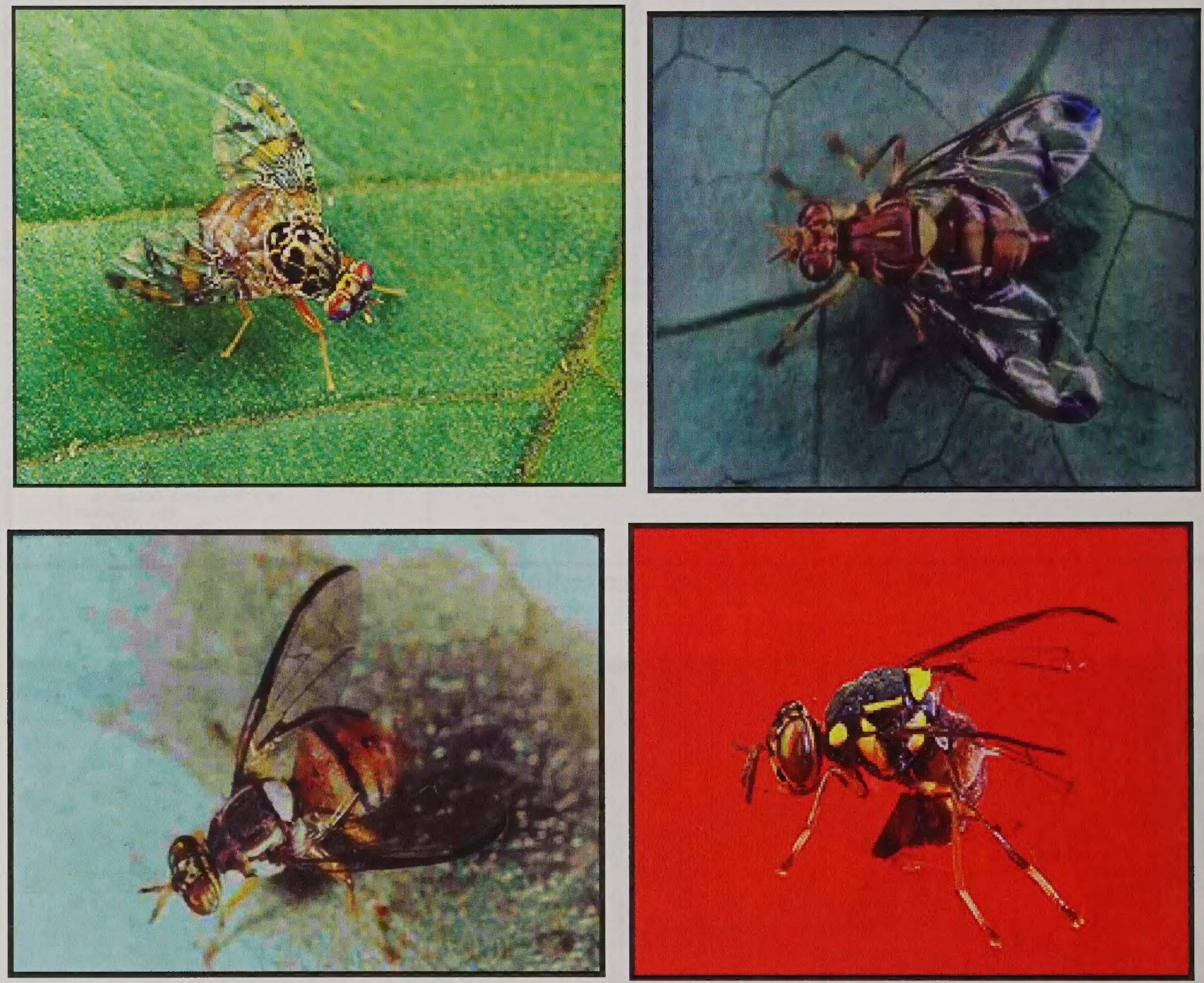
The Hawaii Fruit Flies Laboratory Personnel Chart as of October 10, 1973

Photo taken at Volcano, Hawaii in 1990s. Seated: Terri Stafford, Mark Batchelor; Standing front: Dr. Harvey Chan, Dr. Nicanor Liquido, Charmaine Sylva, Dr. Ernie Harris, Dr. Roger Vargas, Steve Brown, Dr. Roy Cunningham, Dr. Mary Purcell, Lori Carvalho, Esther Schneider, Janice Nagata, Dr. Eric Jang. Standing back: Dr. Grant McQuate, Connie Molarius, Bob Gibbons, Ed Lindsey, Paul Barr, John Ross, Dr. Jack Armstrong, Dr. Steve Peck, and Dr. Don McInnis. E Jang photo.

Directors of the Hawaii Fruit Fly Laboratory		**Directors of PBARC**	
E. A. Back	1912? to 1914	Jerry Quisenberry	1999 to 2001
Unknown	1914 to mid 1940s*	Dennis Gonsalves	2001 to present
Walter Carter	late 1940s to early 1950s		
Lee Roy Christianson	mid to late 1950s		
Loren Steiner	late 1950s to 1960s		
Darrell Chambers	late 1960s to early 1970s		
Ernest Harris	1972 to 1979		
Leroy Williamson	1979 to 1981?		
James Gilmore	1982 to 1988?		
Wendell Snow	1988 to 1991		
Roy Cunningham	1992 to 1996		
Nicanor Liquido	1996 to 1998		

* Unfortunately, many records have been inadvertently disposed of.

FRUIT FLY PESTS OF HAWAII



Top Left: Mediterranean Fruit Fly (Medfly), Top Right: Melon Fly, Bottom Left: Oriental Fruit Fly, Bottom Right: Malaysian Fruit Fly
ARS photos.

The Most Destructive Insect Pests in the Hawaiian Islands